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SIMULTANEOUS LDV MEASUREMENTS OF GAS AND PARTICLE VELOCITIES IN TWO-PHASE FLOW

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ABSTRACT

An experimental investigation was conducted to simultaneously measure the instantaneous velocities of large particles and air in two-phase flow using Laser Doppler Velocimeter. Measurements at different Photo-Multiplier voltage settings are used in separating the signals from the small seeding particles that trace the air flow and the suspended solid particles. The method was applied to obtain measurements in a vertical tunnel for 500 micron particles at different slip velocities. The associated air mean velocity, and turbulent intensity for the flow with and without particles show that the particles reduce the air velocity and increase turbulence intensity near the center.

INTRODUCTION

Two-phase turbulent flow are of considerable engineering importance in a wide range of applications such as rocket motors, ramjet combustion, jet cutting and in jet blast nozzles. Improving the performance of two-phase flow devices requires a knowledge of the instantaneous velocities of gaseous and solid phases. Velocity measurements in two-phase flow fields are complicated by particle-probe interactions and blockage of transmitted and scattered light by the dispersed phase.

Different techniques have been developed for the instantaneous two-phase flow velocities measurements using Laser Doppler Velocimeter (LDV). Lee and Dust [1] developed an electronic processing scheme based on amplitude discrimination and filtering to separate the signals of large and small particles. They measured the velocity of air and glass particles ranging from 100 μm to 800 μm diameter in a vertical pipe flow. Their mean velocity profiles of air and glass spheres results showed increased slip-velocity for larger particles, and a reversed slip-velocity region near the wall in the case of small particles. Tsuji et al [2,3] separated the air and particle velocities by setting threshold values against pedestal and Doppler components of the photo multiplier signals. They measured the velocity of air and plastic particles ranging from 0.2 mm to 4 mm diameter in a vertical pipe. Large particles were found to increase air turbulence through out the pipe section while small particles reduced it. Hussainov et al, [4] used two power lasers with displaced probe volumes of two different sizes to measure the gas and 700 μm glass bead velocity in a vertical downward channel flow. They investigated the modulation of grid-generated turbulence and reported that the large particle caused attenuation of turbulence intensity in the streamwise direction, and decreased the energy spectra at high frequencies.

Larger particle slip velocities occur in supersonic two-phase flows than in the described subsonic flow studies. Hamed et al. [5] predicted particle slip velocities as high as 200 m/s in convergent divergent nozzles, depending on the particle loading and initial conditions. The purpose of the present experimental study is to investigate a method for the separation of large-particle and tracer signals using LDV data obtained from different measuring probe volumes at varying Photo-Multiplier voltage settings for applications involving in high-speed two-phase flow.

EXPERIMENTAL SETUP

A schematic of the test facility is shown in Figure 1. It consists of the following components: particle feeder, main air supply pipe, particle injector, acceleration tunnel, test section, exhaust filter and cyclone.

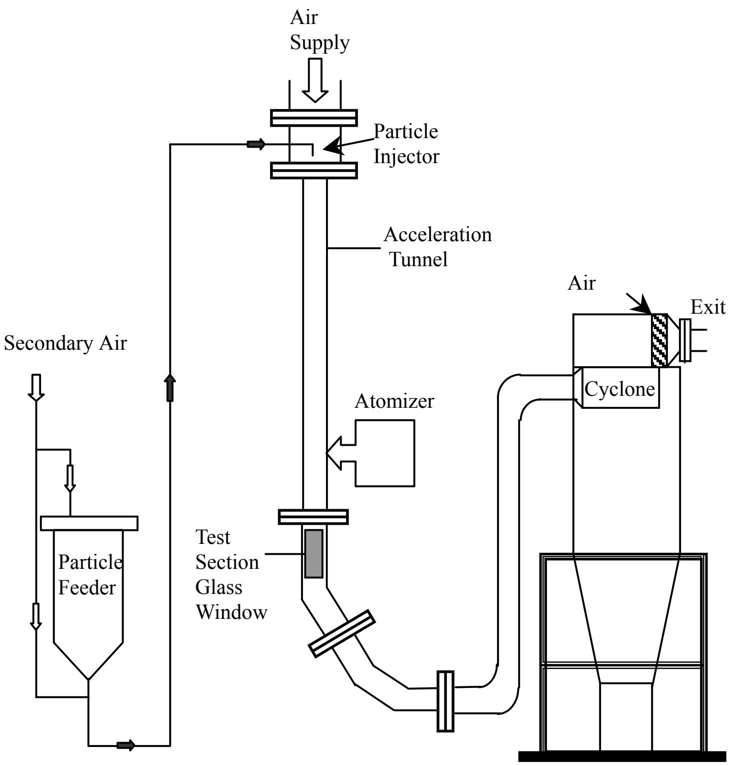

Figure 1. Schematic of test facility

The equipment functions as follows; A measured amount of particles is placed into the particle feeder, where they fed into a secondary air source and blown up to the injector, to mix with the main air supply. The particles are then accelerated by air in a 12 ft long rectangular duct to a test section. The test section is equipped with an optical glass window 6.3 mm thick in order to enable optical access for the Laser Doppler Velocimeter (LDV) measurements. The particles are then separated from the air by cyclone and the filtered air is exhausted at the top of the cyclone into the atmosphere. A TSI 6-jet atomizer filled with propylene glycol aerosol supplied seed particles with mean diameter 1μm. The seed particles were introduced into the flow 12 inch upstream of the test section to measure the air velocities.

The main air is supplied to the facility via a 6-inch diameter pipe from a high-pressure horizontal reservoir, consisting of 7 tanks whose total volume is 102 m^3. The ambient air is pressurizes up to 200 psig then filtered, dried before it is stored in the high-pressure reservoir.

LASER DOPPLER VELOCIMETER SYSTEM (LDV)

A Two-component Laser Doppler Velocimeter system was used in the present study. The blue (488 nm wavelength) and green (514.5 nm wavelength) lines from a 5-Watt Spectra Physics argon-ion laser light source were used to create the LDV measurement volume. The scattered light from the particles in the test section was collected in the backward scattered mode by a 250 mm focal length lens and the system's Real Time Signal Analyzer allowed the reading of the mean velocity, standard deviation, and velocity acquisition rate for each channel. A coincidence, validation criteria was applied by the LDV system to reduce the source of bias inherent in this type of experiment. An event was recognized by the system only if a signal from both channels arrived within a specified time interval. The LDV system with its optical table could move in the axial, traverse and vertical directions with an accuracy of 0.025 mm.

EXPERIMENTAL PROCEDURE

Four sets of LDV measurements were carried out as follows: A. Gaseous-phase measurements in airflow seeded with atomized particles. B. Polydispersed solid-phase measurements in two-phase flow without atomized seeding particles. C. Simultaneous Polydispersed solid and gaseous phase measurements in two-phase flow with atomized seeding particles. D. Same two-phase flow condition as in C, with measurements at a reduced Photo-Multiplier, PM, voltage setting to extract the polydispersed particle velocities from the measured data.

RESULTS AND DISCUSSION

Tests were conducted to characterize the velocity histograms obtained using LDV in gas particle flows, and to establish the requirements of the extraction of the gas and large poly-dispersed particle velocities. The main airflow rate was held constant at 0.1 kg/sec in all the test cases and the air velocity ranged between 60 and 100 m/sec.

Sample histograms obtained at the center of the tunnel are presented in Figures 2 through 5 for the 90 μm particles and 6 through 12 for 500 μm particles at two slip-velocity test conditions. Four histograms are presented as follows:

- **A.** Tracer particle signals in the case of airflow without solid particles.
- **B.** Solid particle signals in the case of two-phase flow tests without tracer particles.
- **C.** Combined tracer and solid particle signals in the case of two-phase flow tests with tracer particles at PM voltage settings of 594.
- **D.** Combined tracer and solid particle signals in the case of two-phase flow tests with tracer particles at PM voltage settings of 248.

The Axial mean and RMS velocities obtained from the histograms are listed in Table 1.

Table 1. Summary of the results obtained at the center of the tunnel.

	Test Case	Mean velocity U_m(m/s)	RMS velocity (m/s)	Turbulence Intensity (RMS/U_m)%
90µm particles	**A**	63.2	6.59	10.4
	B	61.6		
	C			
	Combined	59	8.86	
	D			
	Combined	57.3	9.8	
500µm particles (low-slip velocity)	**A**	63.2	6.59	10.4
	B	18.3		
	C			
	Combined	58.7	11.47	
	Gas	60.9	8.1	13.3
	Particles	18.8		
	D			
	Combined	24.9	16.9	
	Gas	52.9	5.9	
	Particles	17.6		
500µm paricles (high-slip velocity)	**A**	93.9	6.25	6.65
	B	21.3		
	C			
	Combined	72.9	18.1	
	Gas	74	12.5	16.9
	Particles	20.4		
	D			
	Combined	60.5	25.17	
	Gas	72	13.19	
	Particles	21.1		

Results obtained at the center of the constant area tunnel for the 90 micron test case are presented in Figures 2 through 5. Only small differences can be observed between the four histograms due to small slip velocities. It is clear that in this case the particle and gaseous data overlap, making the separation of the two difficult. Results obtained in the constant area tunnel for the 500 micron test case are presented in Figures 6 through 8. Noticeable difference can be seen between the gas and particle histograms of Figures 2 and 6 because the particles lag the air velocity. Figures 7 and 8, for seeded two-phase flow with solid 500 micron particles, show the different velocity histograms obtained at the 594 and 248 PM voltage settings. These figurers demonstrate the reduction in the ratio between the number of detected tracer and lager solid particle signals with decreased PM voltage setting. At the high voltage setting the number of signals from the solid particles is an order of magnitude lower than the number of signals from the tracer particles. On the other hand, the results at the low voltage setting show two distinctly different Gaussian shapes for the tracer and the poly-dispersed particle velocities. Lowering PM voltage setting decreases the measurement probe volume, that means particles would be detected only if they pass nearer to the center of the Gaussian intensity distribution of the measurement volume, which in turn decreases the probability of the tracer particles to be detected (Figure 8).

The influence of the PM voltage on the experimental value of the mean velocity and RMS for the gaseous phase in two-phase flow is summarized in Table 1. A mean velocity of 58.7 m/s is obtained from the combined solid and tracer particle data at high PM voltage, presented in Figure 7. This is only 3% lower than the mean gas velocity of 60.9 m/s extracted from the second Gaussian distribution above cut off value obtained from the data at low PM voltage (Figure 8).

Figures 9 through 12 present sample results for higher two-phase flow velocities with 500 micron solid particles obtained 4 inches downstream of a convergent 3:1 area reduction in the tunnel. Table 1 lists the extracted mean velocity and RMS from the experimental data at the high PM voltage setting. The mean velocity obtain from the combined histograms at high PM voltage is 72.9 m/s, that is only 1.5% lower than the 74 m/s obtained from the second Gaussian distribution above cut off value obtained from the data at low PM voltage (Figure 12). This demonstrates that the error in predicting the gas velocity from the high PM voltage setting decreases with increased slip velocity. Hence in the case of supersonic two-phase flow in convergent-divergent nozzles the error would be much smaller because of the larger slip velocities.

The measured mean particle and axial gas velocity profiles, and turbulence intensity profiles are presented for this case in Figures 13 and 14. As expected the particles reduce the gas velocity. The reduction is larger near the center resulting in flattened gas velocity profile. The large particles also increase the turbulence intensity near the center as shown in Figure 14. These findings are in agreement with the experimental results for gas-particle flows in vertical pipes obtained by Tsuji et al [2,3] using a pedestal and Doppler signal discriminating device, for 500 and 1000 micron particles. According to Core and Crowe [6], the turbulence modification can be attributed to two mechanisms: the acceleration of particles by the fluid (turbulence attenuation) and the creation of wakes as particles move through the fluid (turbulence augmentation). Eaton and John [7], showed that turbulence attenuation increases with the Reynolds number.

CONCLUSIONS

Measurements of the instantaneous velocities of large particles and air in two-phase flow were obtained from the LDV signals at different Photo-Multiplier voltage settings. The large particle data were separated from the LDV histograms at the low voltage setting. The error in computing the mean gas velocity from the combined data at the high voltage setting diminished with increased slip velocities. We plan to further test this method and use it in measuring air and particle velocities in two-phase flow jets of convergent divergent nozzles at different nozzles pressure ratios.

ACKNOWLEDGEMENT

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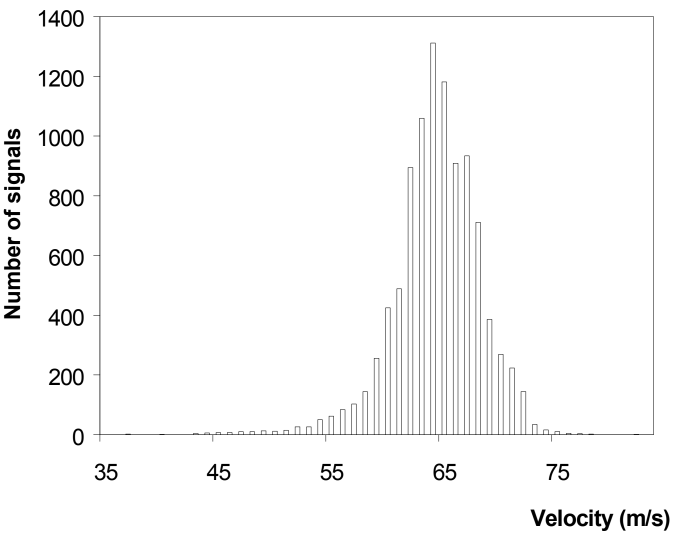

Figure 2. Sample velocity histogram for tracer particles (No slid particles, PM voltage =594).

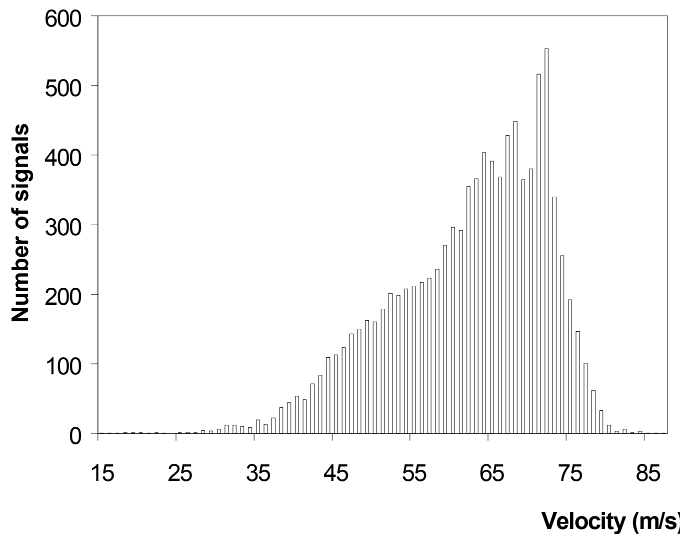

Figure 3. Sample velocity histogram for 90 micron particles (No tracer particles, PM voltage =594).

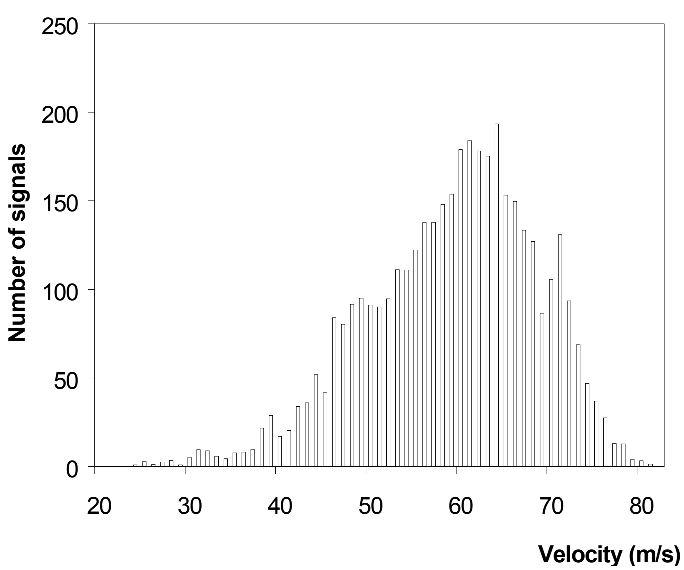

Figure 4. Sample velocity histogram for the combined tracer and 90 micron particles (PM voltage =594).

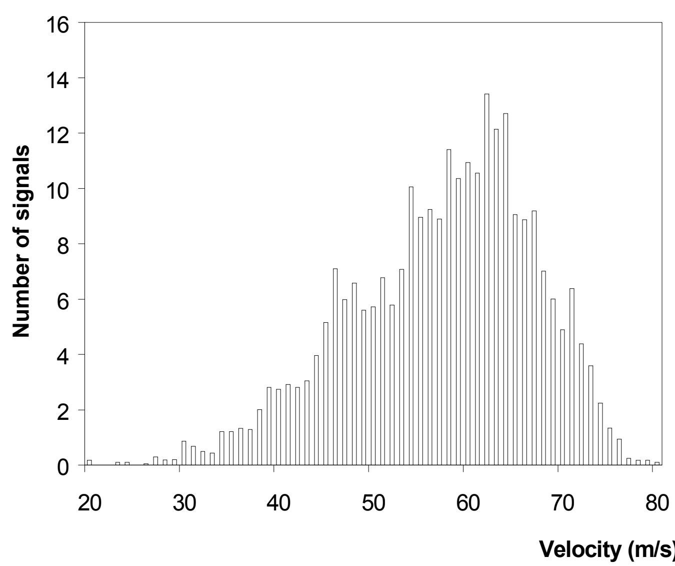

Figure 5. Sample velocity histogram for the combined tracer and 90 micron particles(PM voltage = 248).

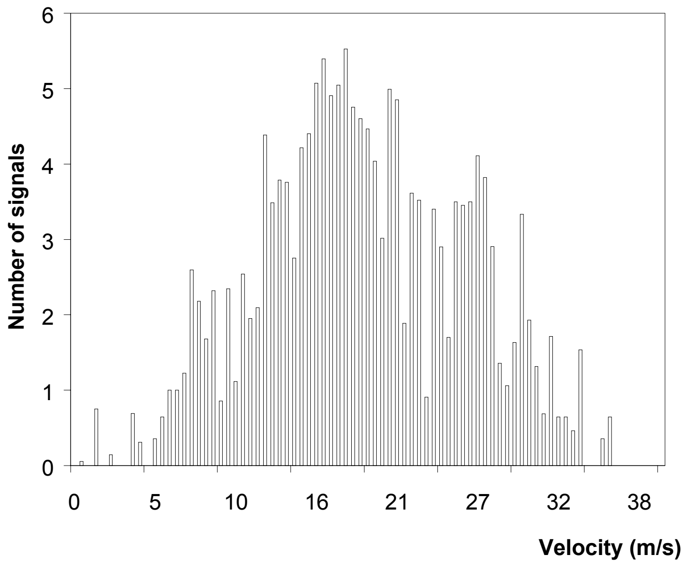

Figure 6. Sample velocity histogram for 500 micron particles (No tracer particles, PM voltage =594).

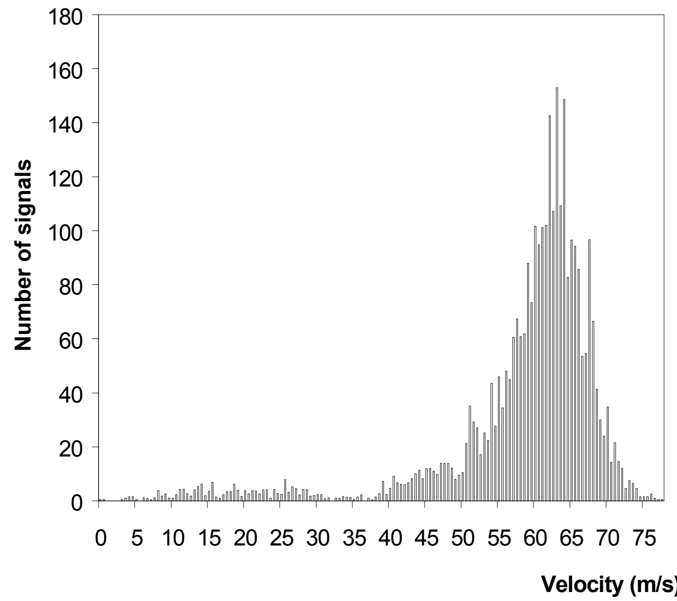

Figure 7. Sample velocity histogram for the combined tracer and 500 micron particles (PM voltage =594).

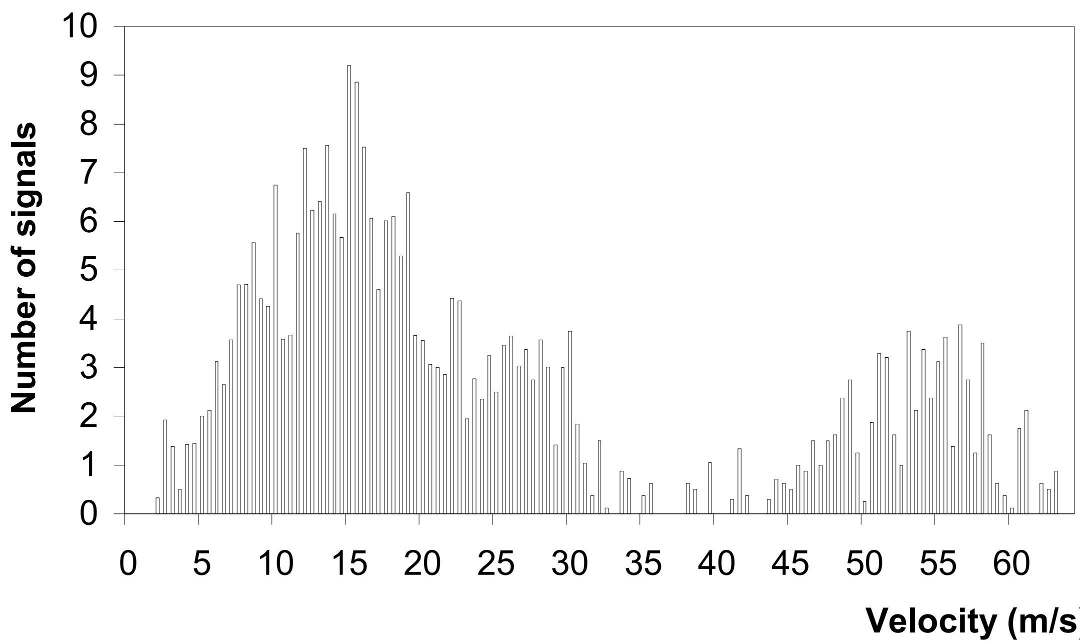

Figure 8. Sample velocity histogram for the combined tracer and 500 micron particles (PM voltage = 248).

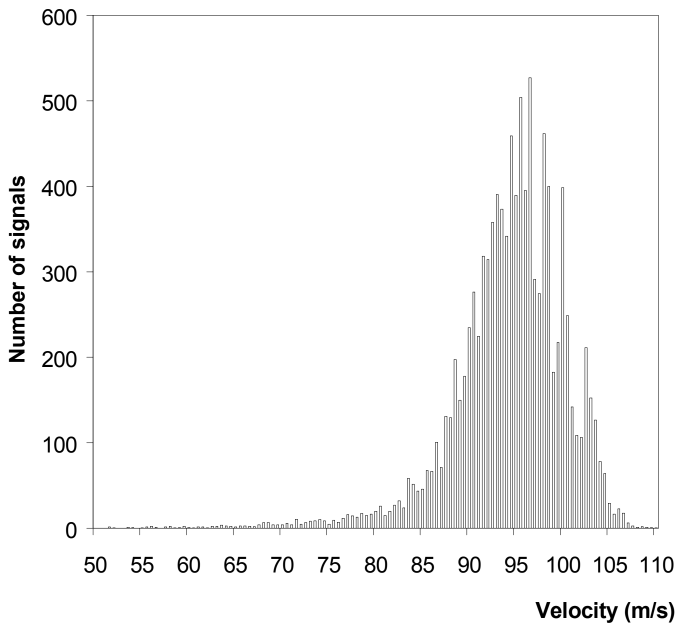

Figure 9. Sample velocity histogram for tracer particles
(No slid particles, PM voltage 594).

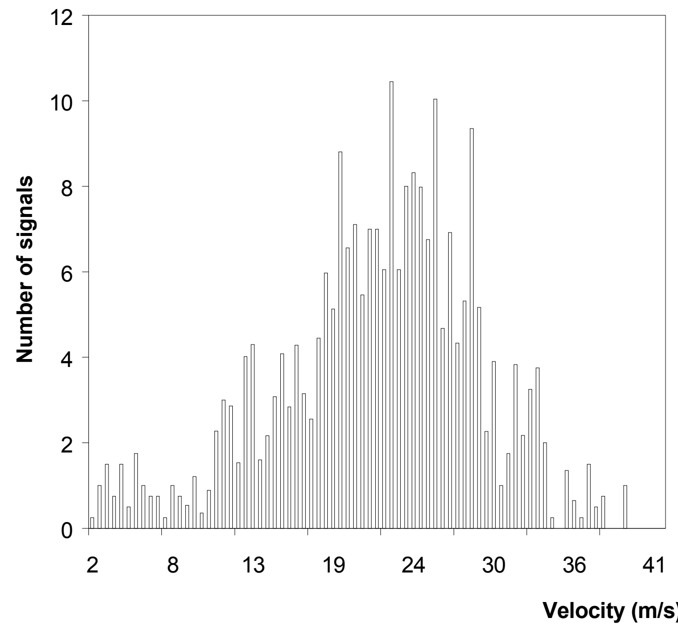

Figure 10. Sample velocity histogram for 500 micron particles
(No tracer particles, PM voltage=594).

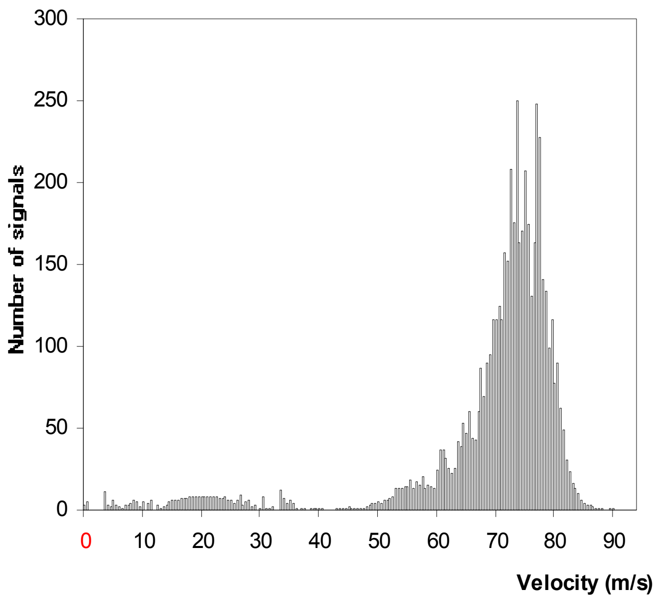

Figure 11. Sample velocity histogram for the combined tracer and 500 micron particles (PM voltage = 594).

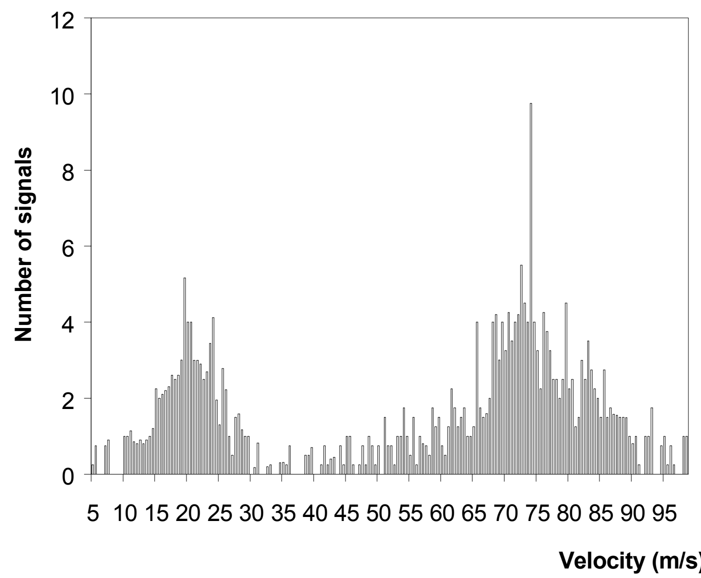

Figure 12. Sample velocity histogram for the combined tracer and 500 micron particles (PM voltage = 248).

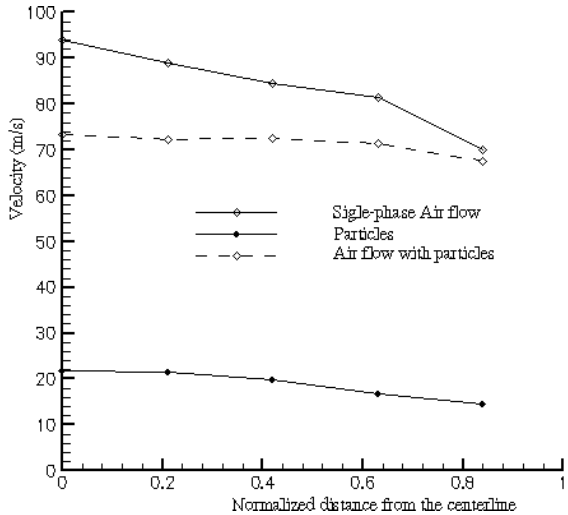

Figure 13. Effect of 500 micron particles on axial velocity profiles.

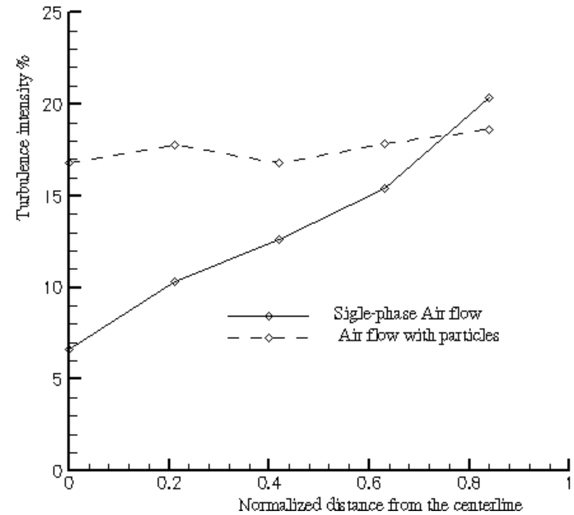

Figure 14. Effect of 500 micron particles on turbulence intensity profiles.