N89-17305

AEROTHERMAL MODELING PROGRAM - PHASE II ELEMENT C: FUEL INJECTOR - AIR SWIRL CHARACTERIZATION

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The main objectives of the NASA-sponsored Aerothermal Modeling Program, Phase II Element C, are to collect benchmark quality data to quantify the fuel spray interaction with the turbulent swirling flows, and to validate current and advanced two-phase flow models. This effort consists of the following five technical tasks.

TASK 1--EXPERIMENTAL CONFIGURATION

A testing facility (Figure 1) was designed to characterize a wide variety of flows under isothermal conditions. The fuel nozzle and swirler combination is operated at both unconfined and confined conditions. The measurements include the following quantities: the three components of mean and root mean square (rms) gas velocity as well as Reynolds stresses, the three components of mean and rms droplet velocity, Sauter mean diameter, droplet size distribution, and cone angle.

All the test configurations (ref 1) are first operated free of injected particles, second with injected monodisperse solid particles (25-micron glass beads), then with two mixed particles (25- and 100-micron beads), and finally with a fuel spray through an airblast atomizer.

TASK 2--MODELING SENSITIVITY ANALYSIS

Computer codes were run to highlight different flow regimes that would be taken into account during data collection.

TASK 3--MEASUREMENTS

A two-component phase/Doppler system (Aerometrics, Inc., Model No. 2100-3) is being used to map out the flow field for both phases. The instrument simultaneously measures size and two orthogonal components of velocity for individual particles. The technique has been evaluated using both laser diffraction and laser visibility techniques in a series of studies (refs 2 and 3). Discrimination of phases or of different sized beads was inherent in the operation of the system. By sizing all particles, statistics are generated for both phases. Aluminum oxide (nominal 2.0 microns) was used to seed the gas phase and, when sized, provides a local peak in size scores substantially less than the local peak for the beads.

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Data are tabulated, and the experiment is documented in Ref 4 following the format outlined in Ref 5. Details of test conditions are given in Ref 1, where the test cases are summarized in Table 1.

Results of cases (1, 2, 7, and 8) are presented below.

TASK 4--RESULTS AND ANALYSIS

Cases 1 and 2 relate to single phase axial and coaxial free jets, respectively; cases 7 and 8 are the corresponding two-phase flow cases with glass beads of 25 microns. The loading ratio (LR), defined as the ratio of particle-to-gas mass flow rate at the inlet plane for cases 7 and 8, are 1.0 and 0.2, respectively. More details for test conditions, data analysis, and model assessment of cases 1 and 7 are presented in Ref 6 while cases 2 and 8 are covered in Ref 7.

Figure 1 shows comparison between predicted and measured values of the mean and gas velocity for cases 1 and 7. It can be seen from Figure 1 that in the particle-laden jet, the gas velocity downstream of the nozzle exit is higher than the single-phase value. At $z/D = 12.45$, an increase of about 20% of the single-phase velocity is caused by the presence of the particles. This phenomenon is explained in detail by Mostafa and Mongia (ref 8) and can be attributed to two effects. One effect is the momentum transfer from the particles to the air since the particle velocity becomes greater than the gas velocity after a short distance downstream of the injector. The other effect is the modulation of the gas turbulence caused by the particles.

Figure 3 corresponds to measurements of the particle mean velocity and number density and shows the predictions with stochastic (ST) and deterministic (DT) treatments. It can be seen from Figure 3 that the ST provides good predictions compared with the experimental data, while the DT performs quite poorly. According to the latter, a particle moves radially due to its initial mean radial velocity and/or the mean radial gas velocity, both of which are small compared with the axial component.

Figures 4 and 5 correspond to Figures 2 and 3 but for coaxial jets and with LR = 0.2 instead of 1.0. Due to the small loading ratio, the effect of the particle on the gas mean velocity is very small (Figure 4). Figure 5 is consistent with Figure 3 in showing the superiority of the ST over DT in predicting particle properties.

TASK 5--MODEL IMPROVEMENT

A mathematical model for turbulent evaporating sprays based on the recent work in that area (ref 8) is being validated in this effort. Figure 6 relates to measurements of the gas kinetic energy and shear stress at LR = 1.0 and shows the predictions with the single-phase K-ε model and its version for two-phase flows. In the latter, the turbulence modulation is simulated by introducing extra terms in the turbulence kinetic energy and its dissipation rate equations. It can be seen from Figure 6 that the single-phase model does not predict the turbulence modulation caused by the particles in the two cases. However, the two-phase flow model yields fairly good comparison with the data. This result confirms our previous findings (e.g., ref 9) that the interaction between the gas and particles is indeed due to both relative mean and fluctuating motion between the two phases, and the turbulence modulation caused by the particles is equally important to the particle's dispersion due to gas turbulence.

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TABLE 1 : TEST CASES

TEST CASE	NOZZLE "FLUID"				SWIRL		CONFINEMENT	
	NONE	PARTICLES: MONO	PARTICLES: MULTI	LIQUID METHANOL	0^o	60^o	457 MM DUCT	152 MM DUCT
AXIAL JET	△				○	□	1 2 3	4 5 6
		△			○	□	7 8 9	10 11 12
			▲		●	■	13 14	15 16
FUEL INJECTOR	△				○	□	17 18 19	20 21 22
				△	○	□	23 24 25	26 27 28

- DATA SETS COLLECTED: 1 - 12
- PRELIMINARY DATA EVALUATION IS COMPLETED FOR CASES: 1, 2, 3, 7, 8, 9
- MODEL EVALUATION EFFORT
  - CASES COMPLETED: 1, 2, 7 & 8

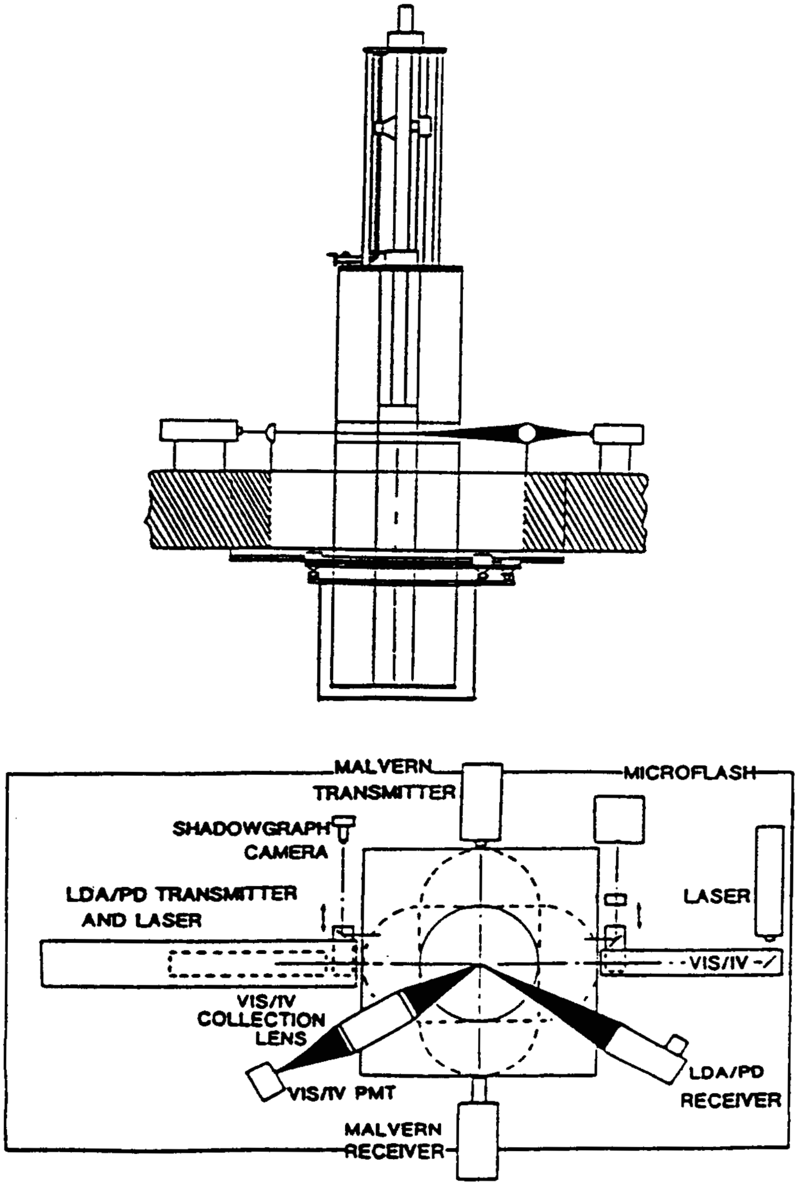


Figure 1. Flow facility and optical arrangement.

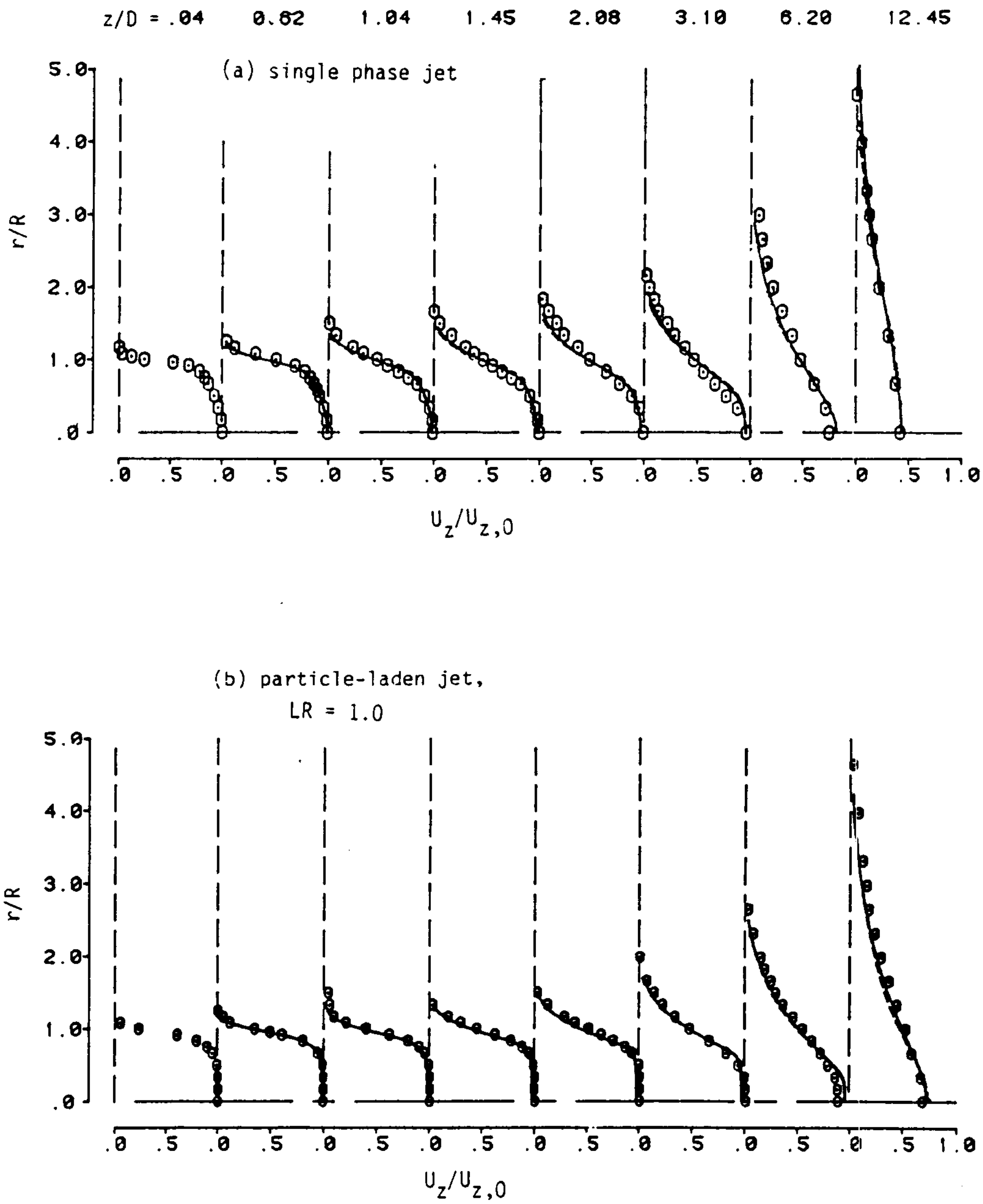


Figure 2. Radial profiles of normalized gas axial velocity for single-phase and particle-laden jet flows.

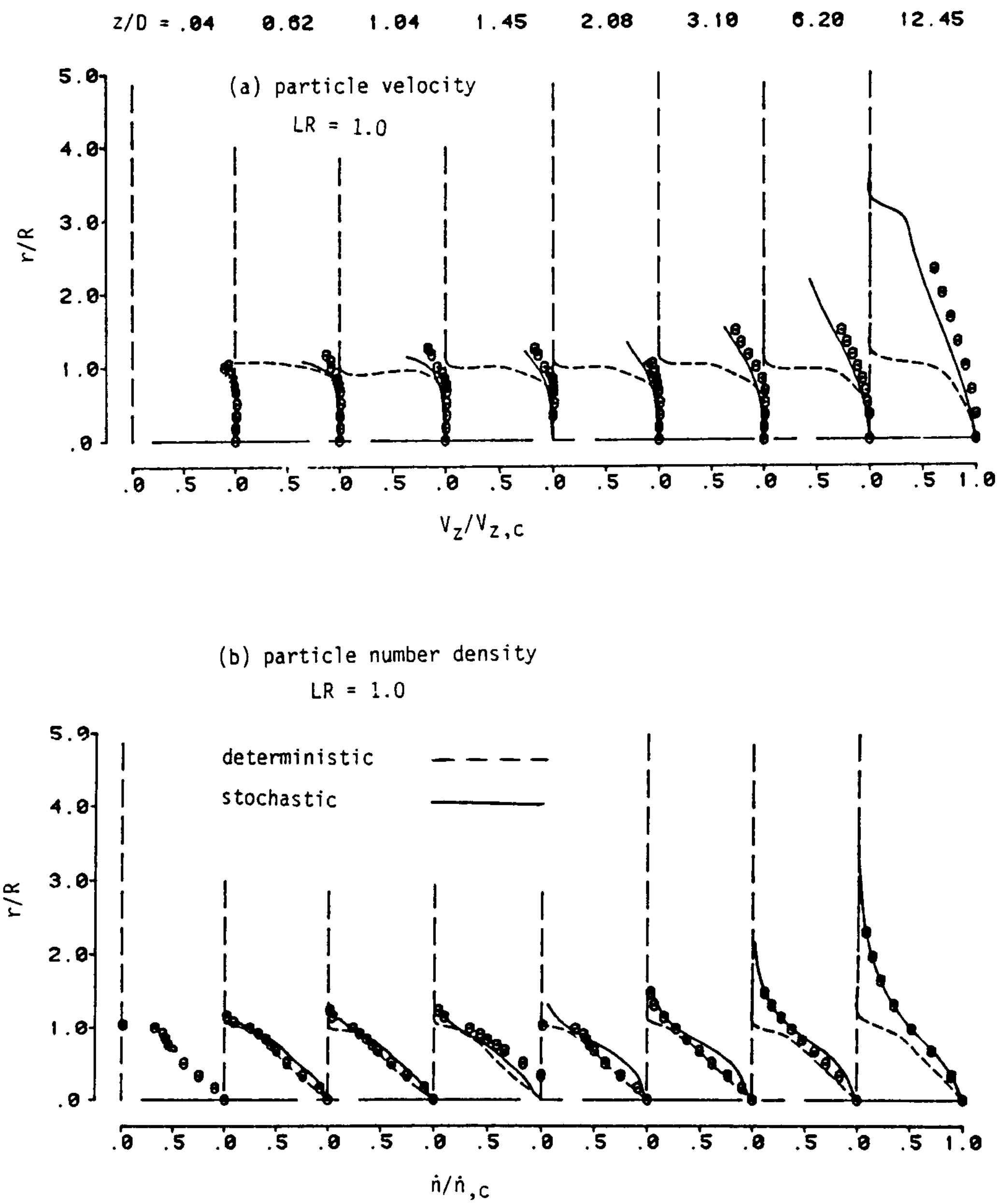


Figure 3. Radial profiles for normalized particle axial velocity and number density for particle-laden jet flows.

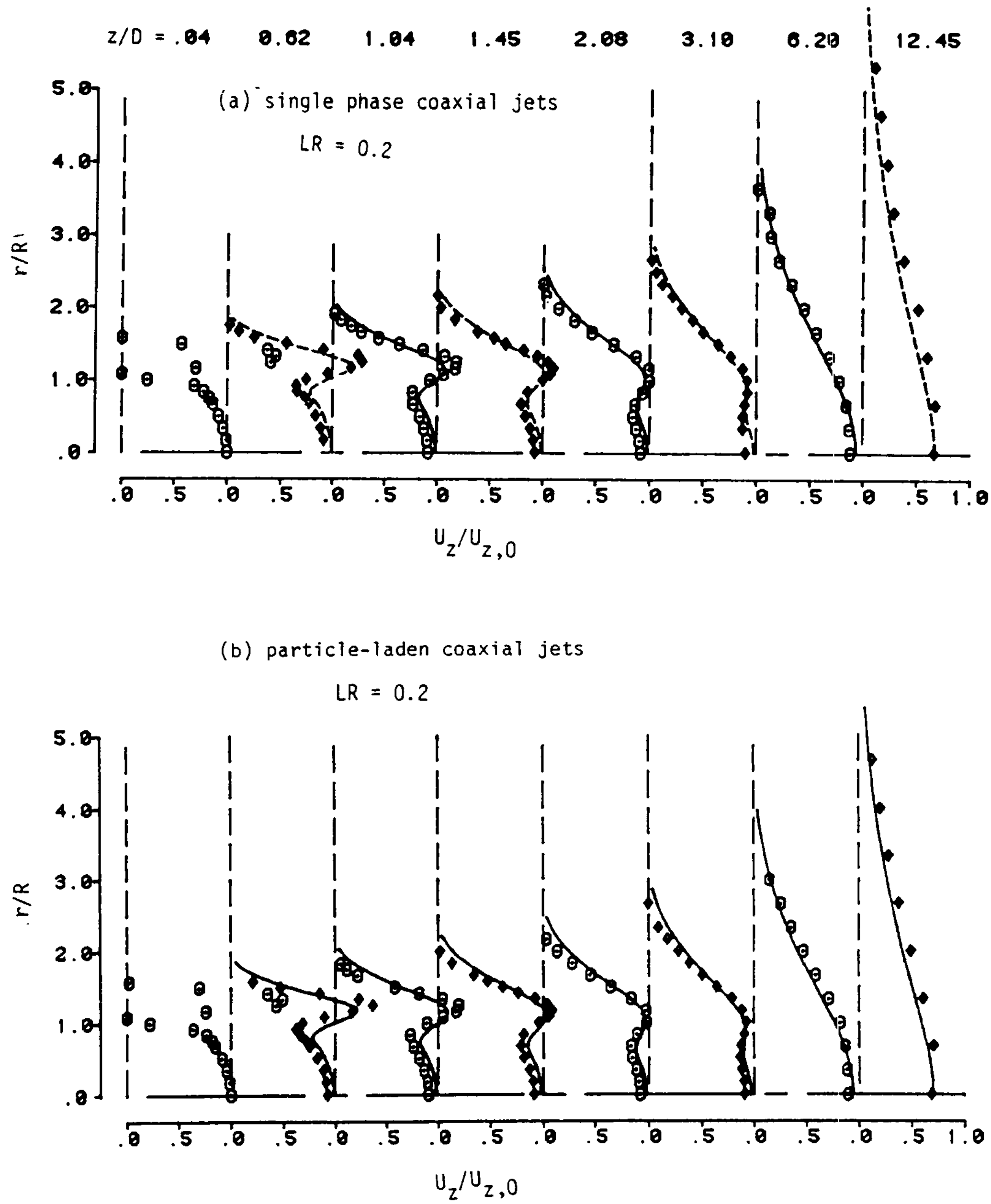


Figure 4. Radial profiles of normalized gas axial velocity for single-phase and particle-laden coaxial jet flows.

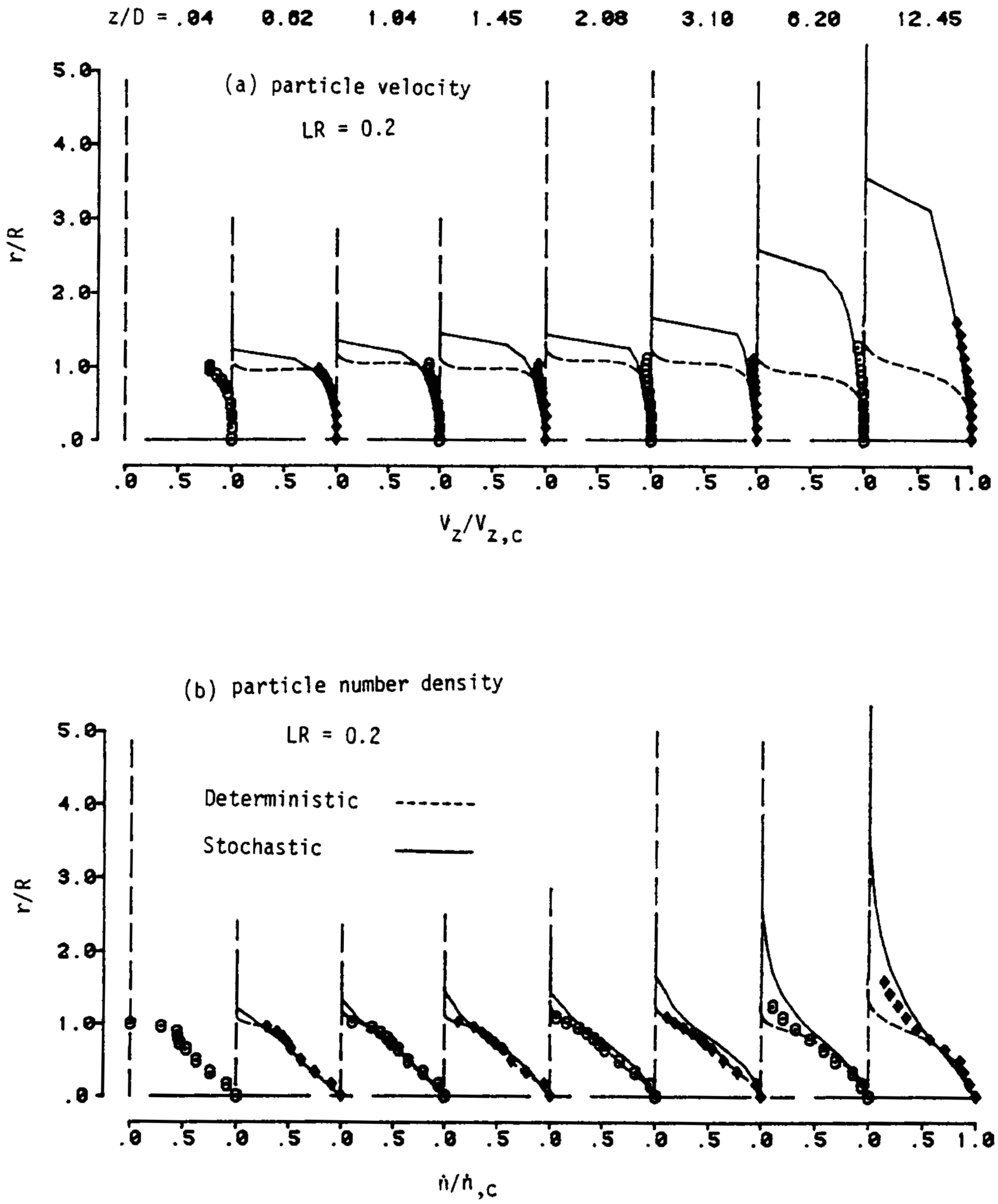
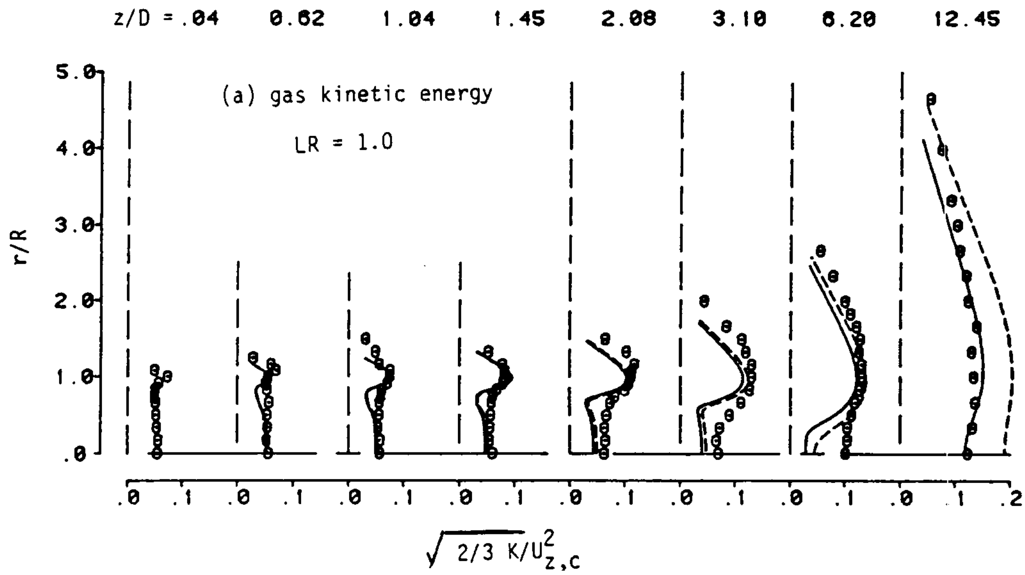


Figure 5. Radial profiles of normalized particle axial velocity and number density for particle-laden coaxial jet flows.



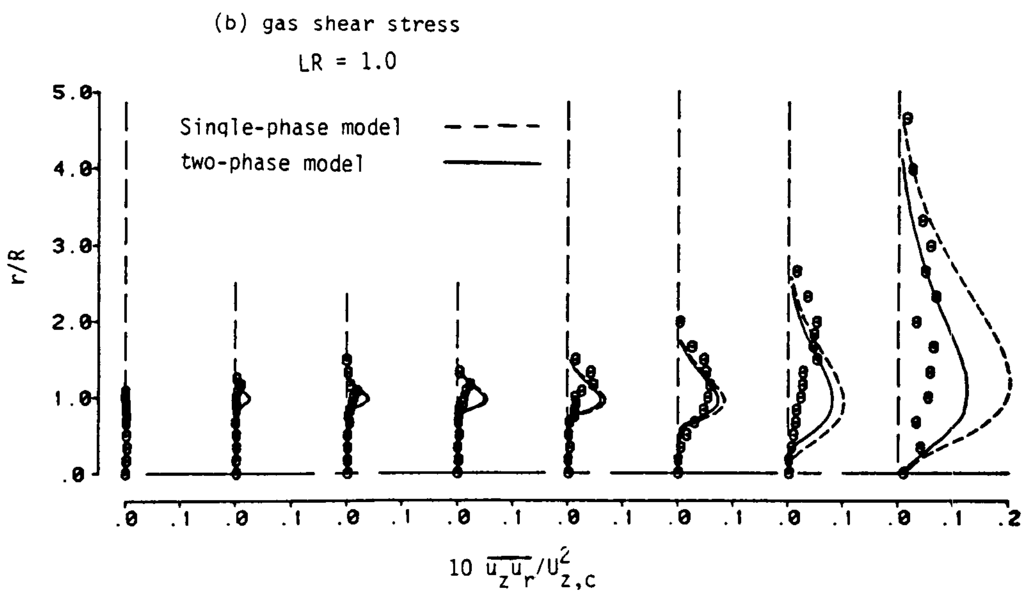


Figure 6. Effect of single-phase and two-phase turbulence models on gas turbulence kinetic energy and shear stress for particle-laden jet at loading ratio, $L_R = 1.0$.