Confined Jet Mixing with Nonparallel Multiple-Port Injection

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Theme

EXTENSIVE experimental studies of the mixing of gaseous, turbulent, coaxial flows have been conducted using configurations in which the primary and secondary systems are parallel.[1] However, very little work has been reported on the mixing of turbulent,particle-laden streams,[2] especially with nonparallel injection of the secondary coaxial jet.[3-4] This synoptic summarizes the results of 40 tests where mixing rates of a primary helium/aluminum particle/air jet with a nonparallel secondary air jet were measured. The air was injected through 4 discrete ports, equally spaced around the primary jet. Injection angle, primary density, and secondary velocity were varied, and mixing rates of the gas and particles were measured. Results are compared with data from continuous, nonparallel injection tests[4] and with coaxial, parallel-flow results.[2]

Contents

The test facility is illustrated in Fig. 1. The 1-in. diam, primary jet was composed of a heated, 2-phase mixture of helium, air, and aluminum powder. The coaxial, secondary jet was unheated air. Gas and particle samples were obtained with isokinetic collection probes located at various radial positions in the secondary duct, and gas velocities were determined from the measured stagnation and static pressures. Test were conducted at various fixed distances aft of the primary nozzle exit. Injection of the secondary air was through a series of 4 equally sized ports located around the periphery of the secondary duct at equal intervals. The cross-sectional area of the port openings was equal to that of the port plugs. Specific design of the port plugs is given in Ref. 5. Injection angles of 30° and 90° were tested. The cross-sectional areas for both primary and secondary flow were held constant as the injection angle was varied. These areas were also equal to those for the previous parallel flow studies,[2] and for nonparallel flow, continuous port injection studies.[4] Since use of the 4 separate ports introduces some 3-dimensional effects, the measured properties of the jet depended upon the orientation of the sample probes with respect to the inlet ports. The following alignment designation is used: "on-portal line" is with the probes in line with the port openings, and "off-portal line" is with the probes in-line with the port plugs.

Forty tests at near-atmospheric pressure were completed during this study. All of the tests were conducted with 20-weight percent of 6-micron (mass mean diam) aluminum powder in the primary jet stream. The gas/particle mixture was initially in dynamic equilibrium at the primary jet exit plane. Four major test variables were investigated: 1) secondary velocity, 2) primary density, 3) secondary injection angle, and 4) test quantity being measured (helium composition, velocity, or particle mass flux). Nominal test conditions for condition A were as follows: primary velocity, 900 fps; temperature, 500°F; helium mole percent, 70; secondary velocity, 125 fps; temperature, 30°F. For condition D they were as follows: primary velocity, 900 fps; temperature, 30°F; helium mole percent, 10; secondary velocity, 400 fps; temperature, 30°F. Material balance errors for particle mass flow rate, total gas mass flow rate, and helium mass flow rate were generally less than ± 10%. In addition, when probe alignment

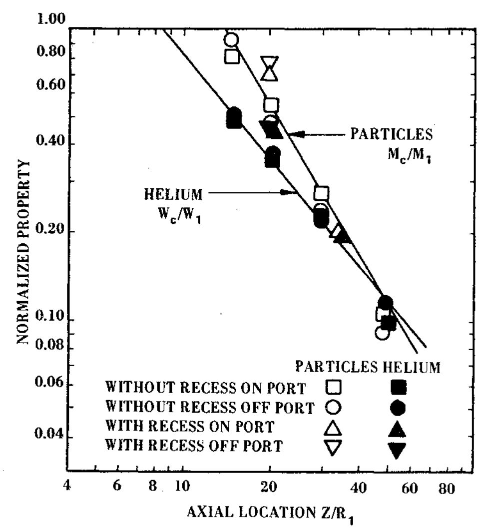

Fig. 2 Centerline decay plot for helium and particle data (Test condition D, 30 degree injection angle, four port injection).

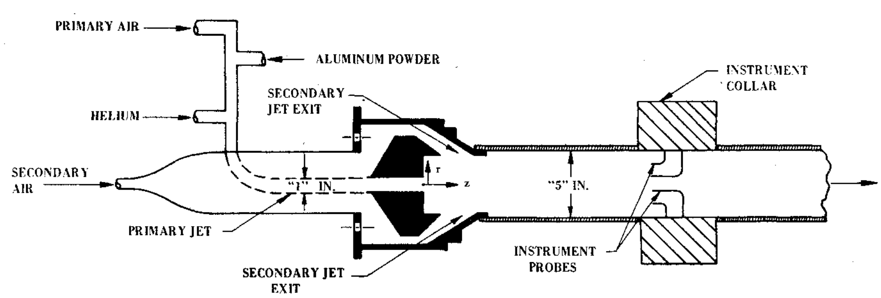

Fig. 1 Schematic diagram of test facility, including nonparallel air injection system.

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Index categories: Jets, Wakes and Viscid-Inviscid Flow Interactions; Multiphase Flows.

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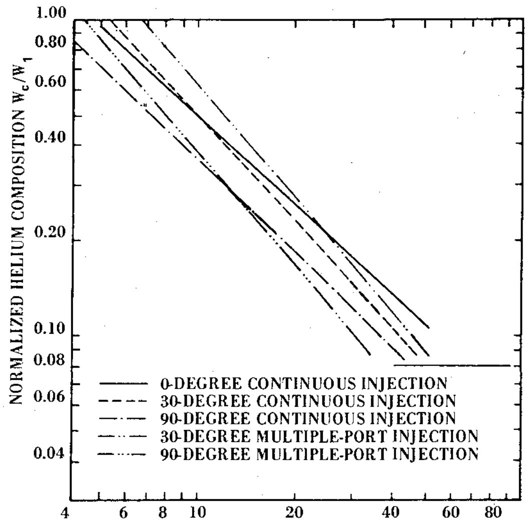

Fig. 3 Effects of injection angle and multiple ports on helium centerline decay (Test Condition A).

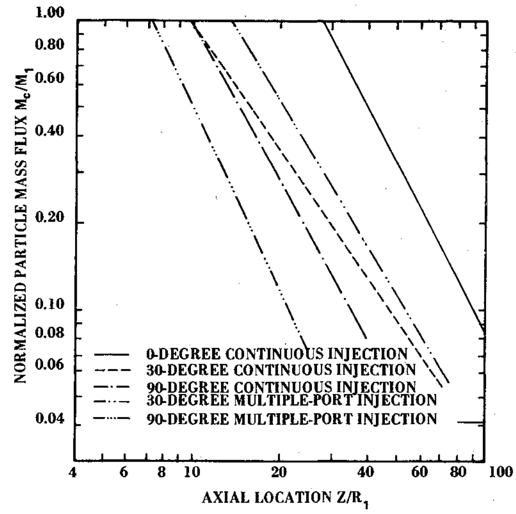

Fig. 5 Effects of injection angle and multiple ports on particle centerline decay (Test Condition D).

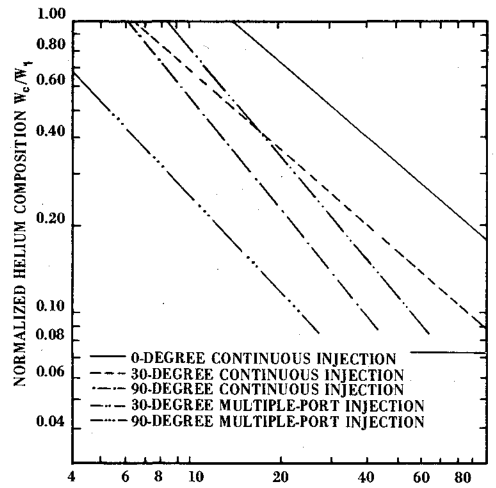

Fig. 4 Effects of injection angle and multiple ports on helium centerline decay (Test Condition D).

was changed from on-portal to off-portal, the probe located on the duct centerline (axis) did not move. Therefore, many additional centerline measurements were reproduced with good accuracy as illustrated in Fig. 2.

Mixing characteristics for these confined jets have been evaluated from analysis of the centerline axial decay of the gas composition, gas velocity, and particle mass flux. Data for all 40 tests are reported in detail elsewhere.[5] For 13 tests, the primary exit was recessed 2.5 in. from the leading edge of the secondary inlet, which formed a small recirculation region shown in Fig. 1. This recirculation region did not greatly affect the rates of mixing, as illustrated in Fig. 2. For both test conditions and both injection angles, mass(helium) mixed most rapidly (see Fig. 2), followed by momentum (velocity) (see Ref. 5) and then particles. These results also show that dispersion of the particles does not follow mixing of the gases. Figures 3-5 show selected test comparisons for helium and particle mass flux data only. These figures illustrate the effect of increasing injection angle. Increasing injection angle caused significant increase in the mixing rates of helium and particles when the secondary velocity and primary density were high (test condition D), but had much less effect when the secondary velocity and primary density were low (test condition A). Smoot and Allred[4] have previously shown for continuous-port, nonparallel injection that systems with low density primary and high velocity secondary mixed most rapidly.

Of principal interest in the multiple-port tests was the influence of the 4 ports as compared to continuous-port injection. Injection area and air velocity and density were the same for the 2 sets of tests. Figures 3-5 compare continuous and multiple-port data for particles and helium. Corresponding comparisons for velocity are shown in Ref. 5. Where nonparallel injection enhances mixing, (such as for test condition D, Figs. 4,5) further enchancement is gained through use of 4 ports, especially for higher injection angles. However, when the rate of mixing is already fast in the parallel flow case (such as test condition A, Fig. 3) use of continuous or 4 port nonparallel injection has only a small effect, and can actually retard the mixing rate. Where mixing was slow for the parallel flow case, increases in mixing rate of as much as 700% were achieved with nonparallel, 4 port injection, as illustrated in Fig. 4. The rate of mixing was particularly rapid for condition D with 90-degree, 4 port injection. Within a secondary duct length to diam ratio of only 3 (i.e.,$Z/R_1 = 30$), the mixing was essentially completed. This mixing rate is even more rapid than for any of the data in condition A, which mixed most rapidly for the parallel flow case. Reference 5 discusses 3-dimensional effects with multiple-port injection and also presents results relating to velocity profiles and to particle size variation due to mixing.

References

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[2] Hedman, Paul O. and Smoot, L. Douglas, "Particle-Gas Dispersion Effects in Confined Coaxial Jets," *AICHE Journal, Vol. 21,* 1975, pp. 372.

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[4] Smoot, L. Douglas and Allred, Larry D., "Particle-Gas Mixing in Confined Nonparallel Coaxial Jets" in *AIAA Journal,* Vol. 13, June 1975, pp. 721-722.

[5] Smoot, L. Douglas, and Fort, Leslie A., "Particle-Gas Mixing in Air-Breathing Ducts with Nonparallel Multiple-Port Air Injection," AIAA Paper 75-246, Pasadena, Calif. 1975