Particle-Gas Mixing in Confined Nonparallel Coaxial Jets

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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 streams are parallel. However, very little work has been reported on the mixing of turbulent particle-laden streams, especially with non-parallel injection of the secondary coaxial jet. This synoptic summarizes the results of 52 tests where mixing rates of a primary helium/aluminum particle/air jet with a secondary, nonparallel air jet were measured. Injection angle, primary density, and secondary velocity were varied and mixing rates of the gas and particles were measured. Results are applicable to the design of airbreathing propulsion systems.

Contents

The test facility is illustrated in Fig. 1. The one-in.-diam, primary jet was composed of a heated, two-phase mixture of helium, air, and aluminum powder. The coaxial, secondary jet was unheated air. The facility was designed to collect radial profile data at various axial locations. Gas and particle samples were obtained with isokinetic collection probes, and gas velocities were determined from the measured stagnation and static pressures. To determine axial profiles, a series of tests was conducted with the instrument collar at various fixed distances aft of the primary nozzle exit.

Injection angles of 0, 30, 60, and 90° were tested. The cross-sectional areas for both primary and secondary flow were held constant as the injection angle was varied. Helium composition was determined by gas chromatographic analysis. Particle mass flux was determined from time for collection of a particle sample and sample weight. Pressure and temperature measurements, together with the throat area of choked control nozzles established the gas flow rates of the primary and secondary iets.

Fifty-two tests at near-atmospheric pressure were completed during this study. All of the tests were conducted with 20 weight per cent of 6-micron aluminum powder in the primary jet stream. 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). Data from two sets of test conditions are

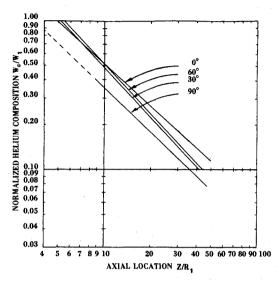
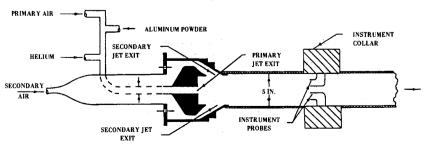


Fig. 2 Effect of injection angle on helium centerline decay (A, 6μ , 20%).

reported in this synoptic: 1) Primary velocity, 900 fps; temperature, $500^{\circ}F$; helium mole percent, 70; secondary velocity, 125 fps; temperature, $30^{\circ}F$; and 2) primary velocity, 900 fps; temperature, $30^{\circ}F$, helium mole percent, 10; secondary velocity, 400 fps, temperature, $30^{\circ}F$. Tests for other conditions are reported by Smoot and Allred. Eight tests were reproduced. Using only the centerline data, the average variation for the reproduced tests was less than 8%, while material balance errors were generally less than $\pm 10\%$. Mixing characteristics for these confined jets have been evaluated from analysis of the centerline axial decay of the gas composition, gas velocity, etc. Data for all 52 tests are reported in detail elsewhere. For 13 tests, the primary exit was recessed 2.5 in. from the leading edge of the secondary inlet, which formed a recirculation region. This recirculation region did not greatly affect the rates of mixing.

Selected test results are summarized in Figs. 2–5. Figure 2 shows only a slight effect of secondary injection angle on helium centerline decay for test condition A. Also, the rate of mixing did

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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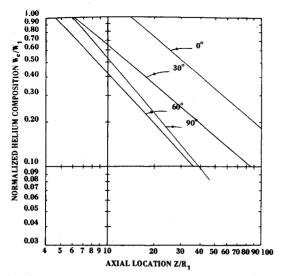


Fig. 3 Effect of injection angle on helium centerline decay (D, 6μ , 20%).

not increase continuously with increasing injection angle. Further, a change of injection angle did not significantly change the slope of the centerline decay. Similar results were observed for the particle and velocity data. Figures 3–5 show the effect of injection angle on helium, velocity, and particle centerline decay, respectively, at test condition D. Here, nonparallel secondary injection greatly increased the rate of mixing. A large increase is observed in going from 0 to 30° for all three variables measured. Particle mass flux was observed to have the steepest decay slope, or the fastest rate of decay. The rates of decay for velocity data were greater than for helium in this case.

The greatest enhancement in mixing rates using nonparallel injection was observed for systems with a high velocity secondary, which mixed slowly in the parallel-flow case. The mixing was greatly enhanced as the high-momentum secondary stream is

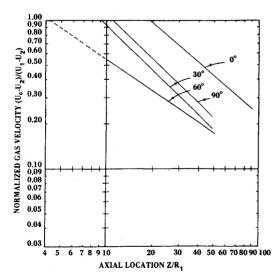


Fig. 4 Effect of injection angle on gas velocity centerline decay $(D, 6\mu, 20\%)$.

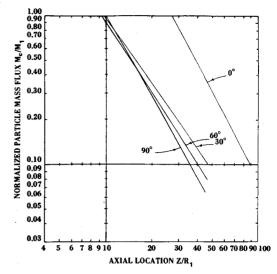


Fig. 5 Effect of injection angle on particle centerline decay (D, 6μ , 20%).

injected into the primary stream. Only slight changes in mixing rates were observed for the conditions which had a low-velocity secondary stream.

The results of this study have suggested the following conclusions. 1) The primary recess had little effect on mixing rates for any of the test conditions. 2) In the gas phase, the mass (helium) mixed more rapidly than did the momentum. 3) The particles generally mixed more slowly than either the helium or gas momentum. 4) While systems with low primary density and low secondary velocity mixed most rapidly with parallel injection. the low density primary, high velocity secondary systems mixed most rapidly with nonparallel injection. 5) The measured effect of variation in initial gas velocity and density on mixing rate was approximately the same for helium composition, gas velocity, and particle mass flux. 6) The most rapid mixing occurred when operating at a low density primary, high velocity secondary, and with a 60° secondary injection angle. 7) The greatest change in rates of mixing was encountered with the initial change from parallel flow to small nonparallel flow angles. 8) Injection angle had little effect upon rates of mixing which were already rapid for parallel injection. 9) The maximum nonparallel rate of mixing did not generally correspond to a maximum secondary injection angle. 10) The rate of decay (centerline slope) did not vary greatly with injection angle, while the rate of mixing (core length) was often a strong function of injection angle.

References

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