Measurement of Gaseous Mixing Downstream of Coaxial and Adjacent Orifices

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Theme

PERFORMANCE in a gaseous propellant rocket is principally related to the rapidity and degree of mixing between the gaseous oxidizer and fuel jet, as opposed to liquid propellant combustion which is primarily vaporization rate limited. Hence, the objective of this study was to experimentally characterize gaseous flowfields from relevant injector elements. For an initial definition of the injector's flowfield, smoke tracers visualized the gas discharge, while pitot probes and catharometers were utilized to measure velocity and mass concentration profiles. These techniques were proven on circular coaxial and rectilinear trislot elements.

Contents

Circular coaxial element—Specific test objectives were: 1) To study the effect of ambient fluid entrainment on the mixing between two axisymmetric, coaxial gas streams. 2) Evaluate the effect of two gas combinations, i.e., He/N_2 and N_2/CO_2 and their respective relative velocities on mixing. 3) Compare the mixing between two different coaxial injector elements: inner tube flush with annulus, inner tube tapered and recessed.

To determine the degree of mixing, axial and radial velocity and mass concentration distributions were measured. The effect of ambient air entrainment on mixing was evaluated by surrounding the flowfield with cylindrical enclosures of varying diameters mounted to the injector face.

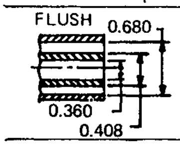
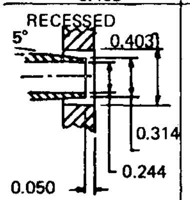
The miniature pitot probe (0.028 in. o.d. × 0.016 in. i.d.) utilized was checked for accuracy and reproducibility by measuring the velocity profile of a free gas jet at the exit of a straight, smooth circular flow tube. The measured velocity varied ±4% over repeat tests.

The index mechanism with the flow model and the pitot probe was mounted on optical rails, facilitating alignment and the axial probe positioning. The flow model could be rectilinearly positioned in orthogonal directions to within 0.001 in. The same probe was used for the gas composition and velocity measurements in the mixing zone. Samples (about 0.016 SCFM) of the local gas mixture were passed into a thermal conductivity gas analysis cell. A Gow-Mac, Model 20-100, gas analyzer with four rhenium-tungsten hot wire elements was used for the concentration measurements.

The test conditions are summarized in Table 1. Initial tests concentrated on the effect of viscous interaction between the discharging gas jets and the surrounding stationary air. This effect is illustrated in Fig. 1, where N_2 and He were flowed at a velocity ratio of 2.04. With no enclosure, the N_2-mass fraction on centerline decreased to about 83%, followed by a gradual increase, which is due to air entrainment (the analyzer cannot distinguish between air and N_2 because the thermal conductivities are essentially equal). Eliminating air entrainment by surrounding the flowfield with a 1¾-in.-diam enclosure (8 in. long) yielded a concentration curve which approached a constant value of 58.2%. This value agreed within the analyzer's accuracy of ±2½%, with the calculated N_2-mass fraction of 59.8% based on the metered flowrate. Some air entrainment, however, still existed for mixing tests with the 4-in.-diam enclosure.

The effect of velocity ratio (annular—to inner jet) and different gas combination on mixing is demonstrated in Fig. 2, representing the centerline gas composition as a function of

Table 1 Summary of test conditions

Injector Element	Inside Gas	Outside Gas	Peak Velocity Inside, V_i (FPS)	Peak Velocity Outside, V_o (FPS)	V_o/V_i	$\rho_o V_o / \rho_i V_i$	Mixture Ratio m_i/m_o	Calculated Mass Fraction Inside Gas
FLUSH 	N_2	H_e	150	318	2.04	0.284	1.49	59.8%
	N_2	H_e	150	318	2.04	0.284	1.49	59.8%
	N_2	H_e	150	318	2.04	0.284	1.49	59.8%
RECESSED 	N_2	H_e	441	612	1.39	0.197	4.64	82.3%
	N_2	H_e	491	1000	2.04	0.289	3.27	76.6%
	N_2	H_e	435	1322	3.04	0.431	2.23	69.0%
	CO_2	N_2	591	612	1.04	0.658	1.69	62.8%
	CO_2	N_2	441	612	1.40	0.877	1.45	59.2%
	CO_2	N_2	441	385	0.87	0.556	2.13	68.0%

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Index category: Jets, Wakes, and Viscid-Inviscid Flow Interactions.

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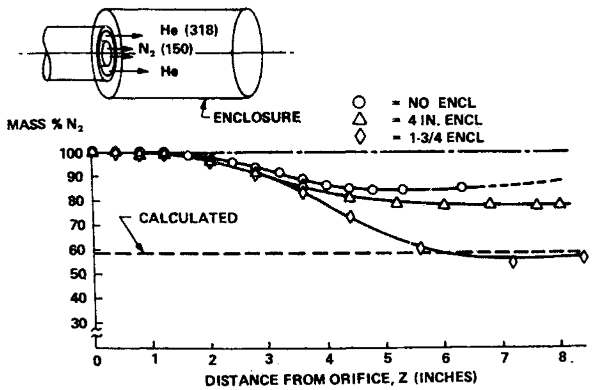

Fig. 1 Effect of enclosure size on the centerline gas composition variation with axial distance from orifice.

distance from the orifice. It shows that the mass potential core (region at the center of the inner jet not influenced by the outer jet) extends further downstream for decreasing velocity ratio, V_0/V_i, or decreasing mass flux ratio (see Table 1). This effect is more obvious for the N_2/CO_2 case. Also the mixing rate increased with increasing velocity ratio. In all cases the gas concentration became uniform with increasing axial distance, which agreed with the value (indicated by the dashed horizontal line), calculated from the known mixture ratio. An interesting unexpected observation resulted when a gas combination of less differing densities, yet greater mass flux ratio, was flowed: the mixing was considerably improved, resulting in a uniform mass concentration much closer to the injector. Similar results were noted from radial composition and velocity profiles and are reported in the AIAA Paper 71-675.

Limited tests were conducted to investigate the effect of

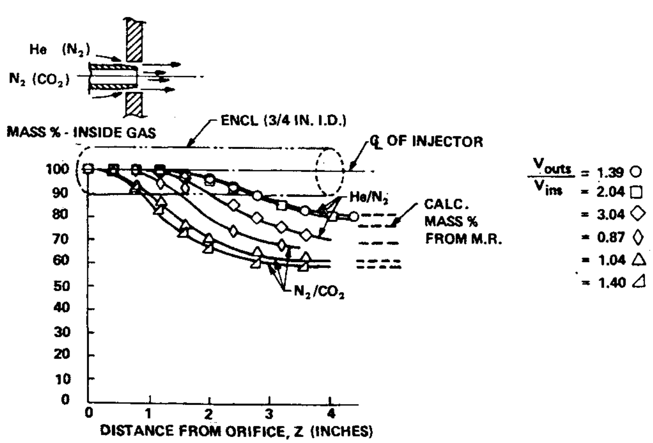

Fig. 2 Effect of velocity ratio and gas combination on centerline gas composition change with axial distance.

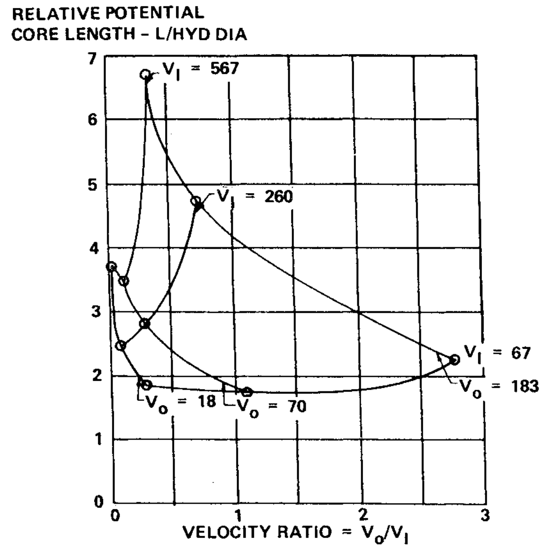

Fig. 3 Effect of gas velocity on potential core length.

recessing the inner post of the coaxial injector on the mixing performance. Tentative results concluded that mixing was improved only slightly by recessing $\frac{1}{16}$in. and tapering the inside orifice.

Trislot element—For a quick assessment of gas jet mixing from asymmetric orifices, it was found that visualization techniques could expediently define the potential core. A triplet configuration, three parallel adjacent sheets, was studied since the potential core is readily observable. The advantages of such an element are fully explained in the paper. The purpose of these tests was to study the effect of relative jet velocities on the potential core of 3 adjacent slots. The trislot element was built by sandwiching three rectangular tubes (0.64in. $\times$ 0.20in.; 0.005in. land thickness) along the wider dimension. The set-up was such that the gas flow through the two outer orifices could be controlled independently from the gas flow through the inner slot. A "Taylor" Smoke Generator was connected to the gas lines upstream of the injector to visualize either the outside or inside efflux. This generator produced white, low density smoke by mixing and boiling a mineral oil with an inert gas in a mixing chamber. Top lighting and a black velvet background yielded a good contrast of the visible flow expansion. For this test series, smoke was injected into both outside streams of gaseous N_2, whereas unmarked gaseous N_2 was flowed through the center. The results indicated that, as expected, increasing the inside jet velocity increases the length of the potential core, but also that raising the outside jet velocity had a similar effect. Increasing the ratio of outside to inside jet velocity tended to lengthen the potential core, but the effect is not as strong as that of velocity itself. Of course, lengthening of the potential core means decreased mixing effectiveness. Figure 3 summarizes the test results.