

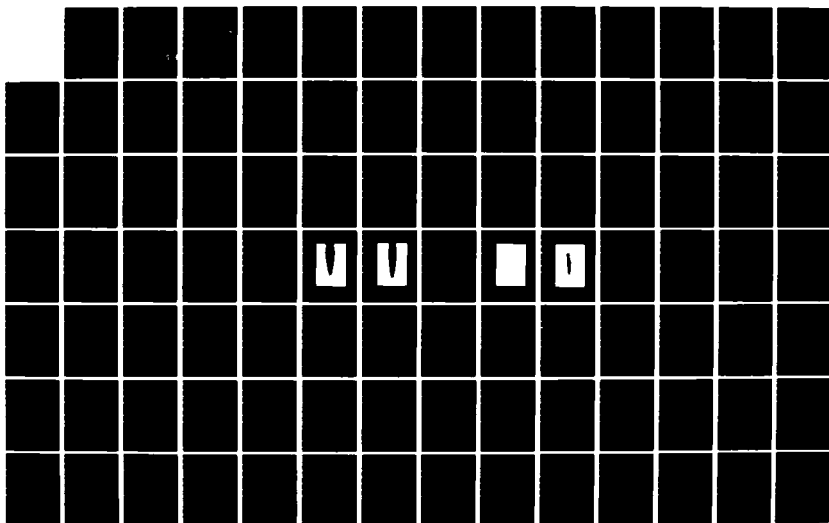
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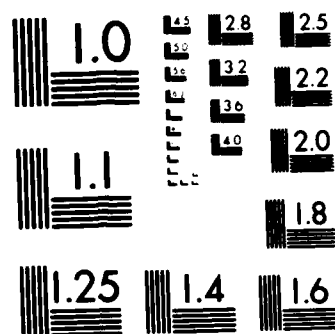
DENSITY AND CONFINEMENT EFFECTS ON MIXING
CHARACTERISTICS OF AN AXISYMMET. (U) AIR FORCE INST OF
TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI. J H DOTY
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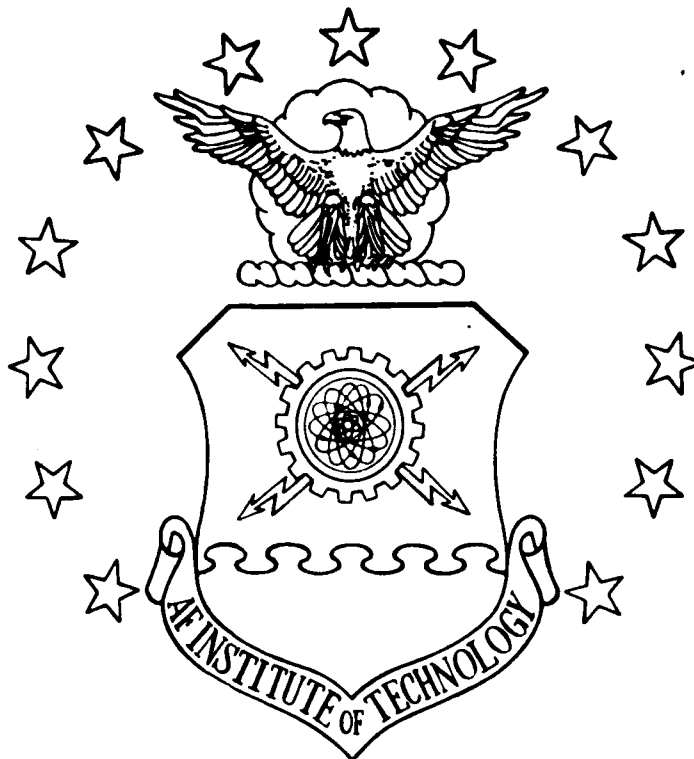
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DENSITY AND CONFINEMENT EFFECTS ON MIXING
CHARACTERISTICS OF AN AXISYMMETRICAL
CO₂ JET

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DENSITY AND CONFINEMENT EFFECTS ON MIXING CHARACTERISTICS
OF AN AXISYMMETRICAL CO₂ JET

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute Of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Aeronautical Engineering

John H. Doty, B.S. Chem E, B.S. AE
First Lieutenant, USAF

March 1985

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John H. Doty

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LIST OF SYMBOLS

a	virtual origin of jet
A	centerline velocity decay parameter
C_2	entrainment growth characteristic
D	nozzle diameter (0.48cm)
f_{msf}	mass fraction
m	mass flow rate
m_0	initial mass flow rate
MW	molecular weight
P	static pressure
P_T	total pressure
$\Delta P, DP$	dynamic pressure (total-static)
Q	volumetric flow rate
r	radial distance
$\bar{R}$	universal gas constant
T	absolute temperature
U	axial component of velocity
U_0	inlet velocity
U_{max}	centerline velocity
X	axial distance
ξ	similarity variable
ρ	density of mixture
ρ_0	initial jet density
ρ_s	density of surrounding medium
σ	similarity constant
x	mole fraction

ABSTRACT

The effects of jet density and confinement on spreading and entrainment rate of an axisymmetrical CO_2 jet in air were studied. Four tests were conducted to isolate these effects: heated free jet; isothermal free jet; heated confined jet; and isothermal confined jet. The mass flow rate of CO_2 was held constant for all tests at 6 kg/hr. Flow visualization studies were also conducted to corroborate important results.

It was determined that isokinetic sampling for CO_2 concentrations is important for obtaining accurate measurements in the jet shear layer for axial distances less than 10 jet diameters.

An increase in velocity at the edge of the jet near the entrance plane was noted for the isothermal studies where the density difference between the jet and the surrounding air was significant.

Spreading rate for the jets was determined using the half width at half maximum criterion. In all four tests it was determined that the scalars of temperature and CO_2 spread at the same rate, less than velocity in the initial jet regions and greater than velocity in the fully developed regions of the jet. Also, the heated jet spread slower than the isothermal jet; and the confinement imposed noticeable restrictions on the spreading and entrainment rates of the jet.

The heated jet entrained more air than the isothermal jet at the same axial location even though the heated jet had a smaller cross sectional area. In addition, the free jet entrained almost 60% more air than the confined jet.

I. INTRODUCTION

Two important parameters that influence the mixing characteristics of a jet are the presence of a confinement and density difference between the jet and its surroundings. The effect of a confinement on the spread of a jet was studied by Lightman and Roquemore in their investigation of a CO_2 jet in a research combustion tunnel (1). They concluded that velocity and mass transported at nearly the same rate, which contradicts results by Keagy and Weller (2) (using a free CO_2 jet) showing that mass is transported more rapidly than velocity. In addition, Ricou and Spalding (3) have determined that the density of a jet relative to its surroundings affects entrainment by the jet.

This investigation had two major objectives:

1. Determine the effect of a confinement on the spreading and entrainment rate of a CO_2 jet.
2. Study the effect of jet density relative to its surroundings on the spreading and entrainment rate of a CO_2 jet.

The first objective was accomplished by performing measurements of velocity and CO_2 concentration for a confined and a free CO_2 jet. The confinement was the same research combustion tunnel used by Lightman and Roquemore in their study.

The second objective was reached by heating the CO_2 jet until its density was equal to that of the surrounding ambient air. Then measurements of velocity, temperature, and CO_2 concentration were taken

for the confined and free jets. Comparisons were made between all four test cases to determine the effects of the confinement and jet density.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

Combustion Tunnel

Confined jet studies were conducted in the APL combustion tunnel shown schematically in Figure 1. Air flowed through the annulus region at an average axial velocity of 1 m/s and CO_2 issued from the nozzle in the center of the bluff body. The dimensions of the duct, centerbody, and nozzle are 30.5 cm, 14 cm, and 0.48 cm, respectively. The nozzle met ASME Power Test Code 19.5, 4-1959; low beta series long radius flow nozzles that produce flat exit profiles with thin boundary layers, (1).

Free Jet Stand

The test stand shown schematically in Figure 2 was constructed for the free jet studies to support the probe traverser and nozzle assembly. A face plate of the same diameter as the bluff body was made to mount the nozzle and provide radial air flow patterns similar to the confined jet. The air flow for the free jet studies was established by the aspirating nature of the jet, rather than forced air for the confined jet studies. The nozzle was situated at the back of the stand such that the exiting CO_2 could escape freely through the opening in the front of the frame.

Flow Visualization

Qualitative assessments of spreading and entrainment for the free jet studies were conducted through flow visualization. The apparatus used for these tests is shown in Figure 3. The CO_2 was dried, then seeded with titanium tetrachloride (TiCl_4) which reacts with moisture in the entrained air to form titanium dioxide (TiO_2), a visible white powder. A low energy laser was then directed through a cylindrical

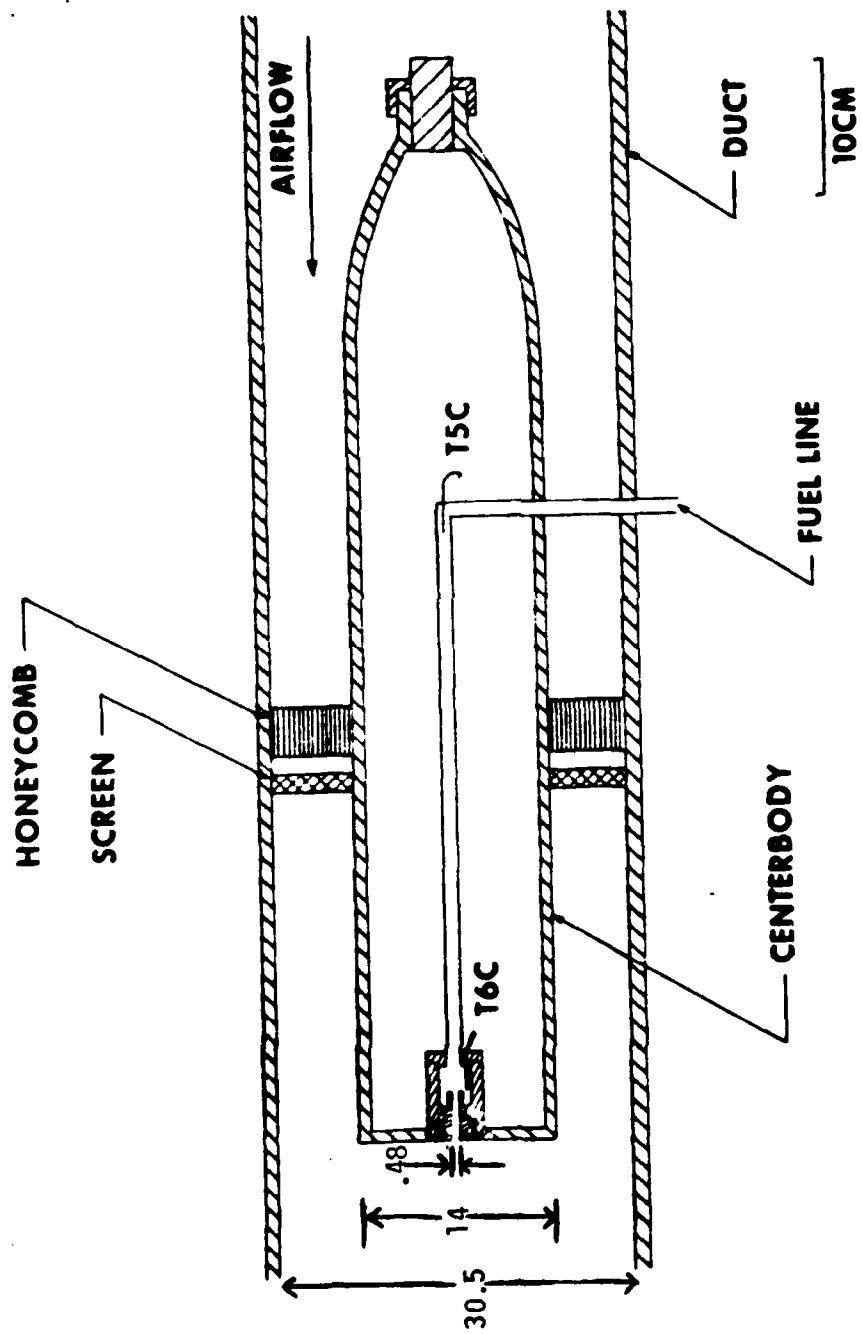


FIGURE 1
Combustion Tunnel

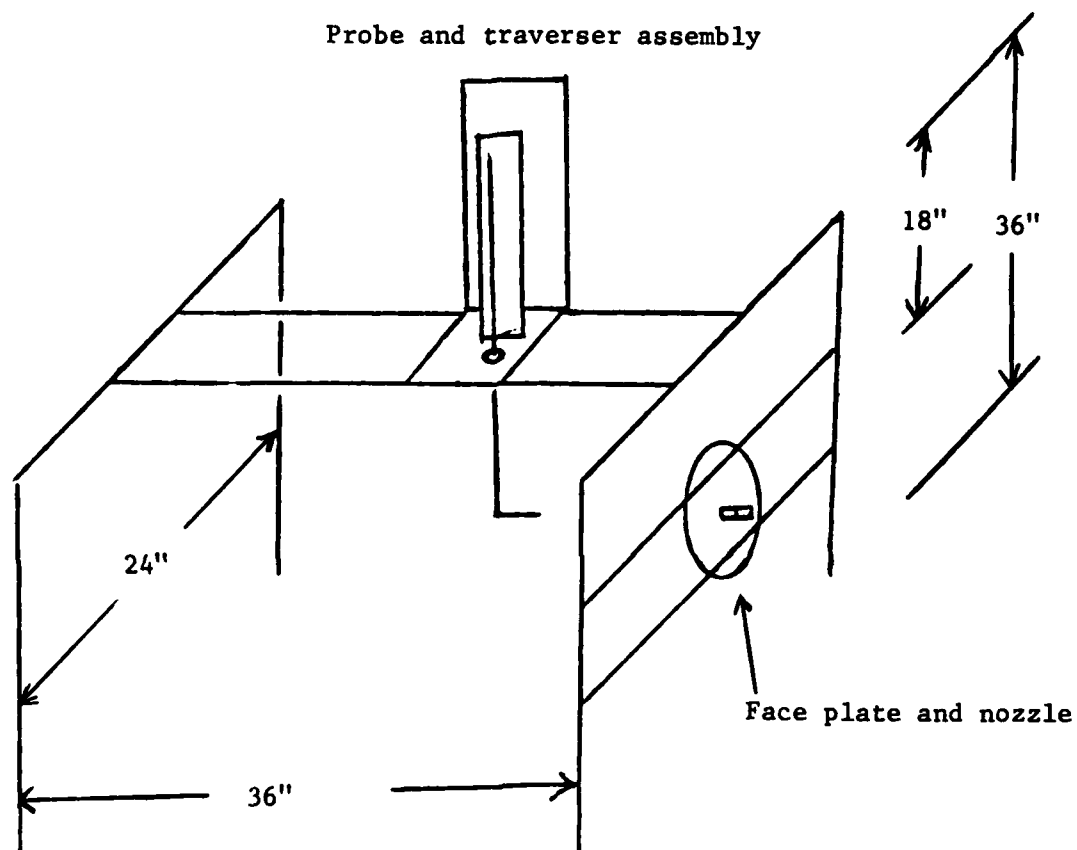


FIGURE 2
Free Jet Stand

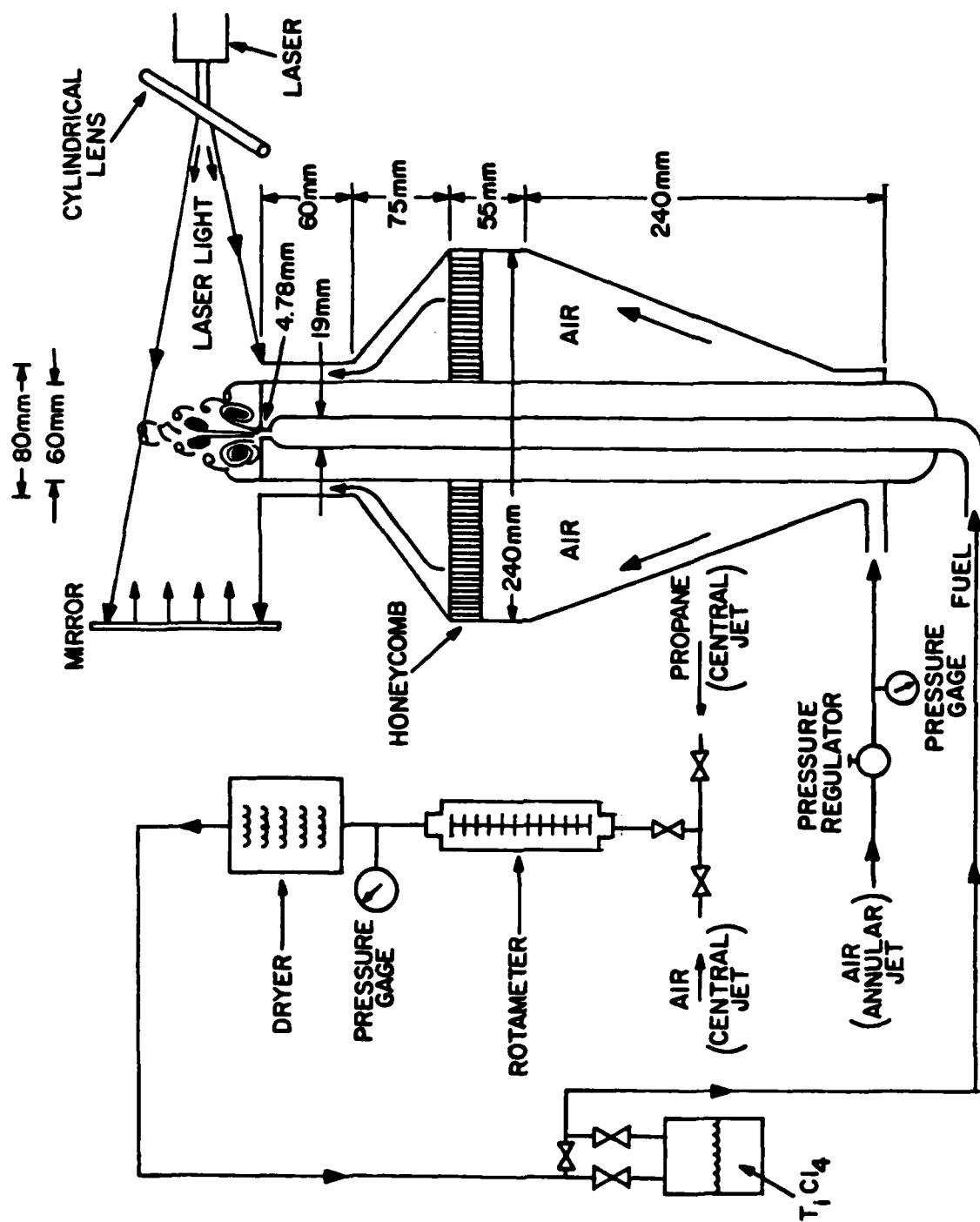


FIGURE 3
Flow Visualization Apparatus

glass rod resulting in a "sheet" of light which was then passed through the jet, producing a 2-D image.

Sample Probe

A pitot-static probe was modified to allow CO₂ sampling and temperature measurements to be made in addition to total and static pressures. Figure 4 shows the probe before and after modification. The pitot line was fitted with a three-way valve so that total pressure and CO₂ samples could be taken alternately. Also, a 5 cm long brass tube was inserted into the pitot port of the probe to reduce the OD from 0.3175 cm to 0.11 cm and ID from 0.11 cm to 0.05 cm. This decrease in frontal area reduced the flow disturbance effects as suggested by Yanagi (4). A small diameter (0.01 cm) type-K thermocouple was then attached to the leading edge of the brass tube in order to measure the temperature of the jet.

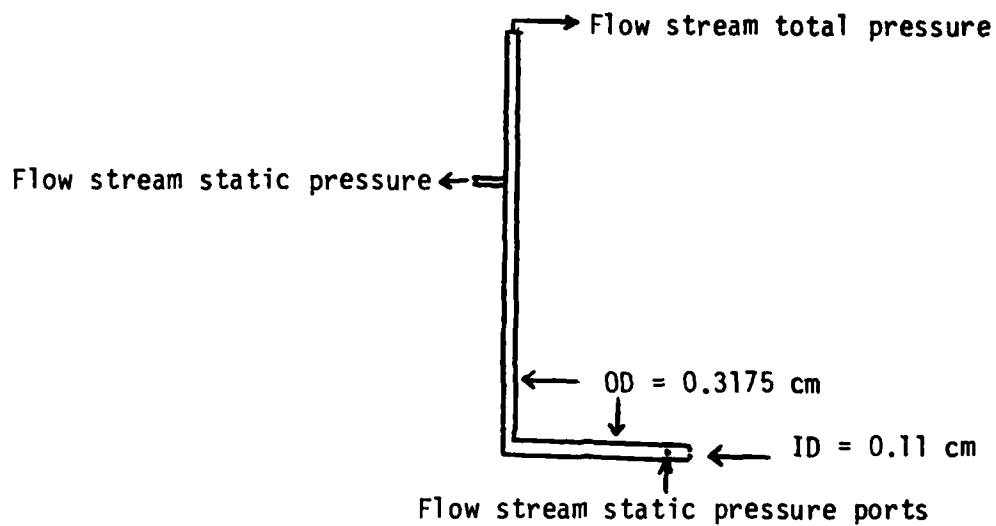
Isokinetic Gas Sampling Technique

Isokinetic sampling occurs when the velocities of the flow stream and the gas sample are the same. The qualitative effect of sampling at velocities higher, equal to, or lower than the flow stream is shown in Figure 5.

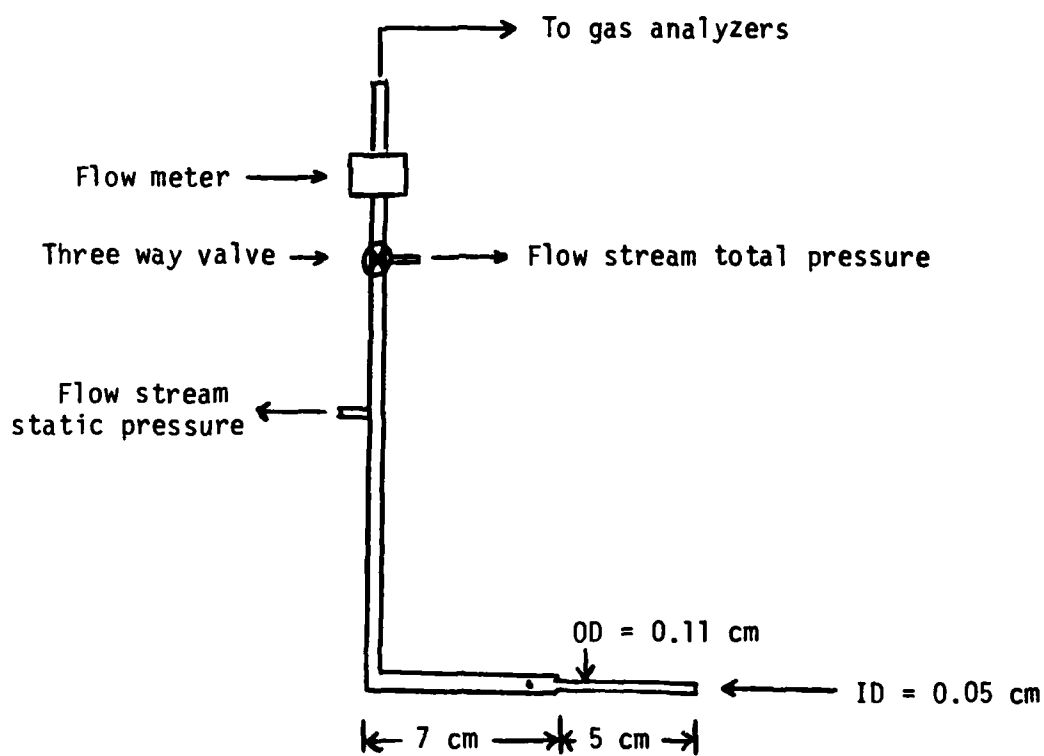
The superisokinetic sampling method (velocity higher than flow stream) increases the capture area of the probe whereas the subisokinetic sampling technique (velocity less than flow stream) has the opposite effect.

The velocity of the gas sample was determined by measuring the volumetric flow rate (Q) with a rotameter as shown in Figure 4 and then using the relationship

$$U_{\text{sample}} = (\text{Volumetric Flow Rate})/(\text{Probe Inlet Area})$$



A. Before modification (not to scale)

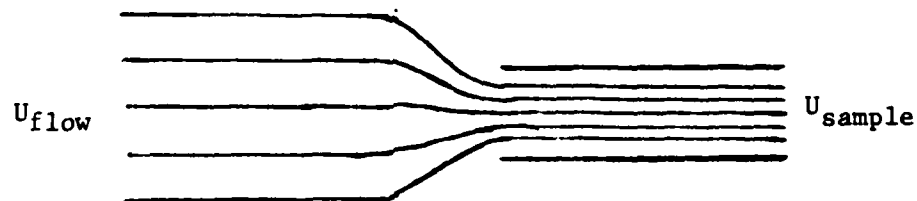


B. After modification (not to scale)

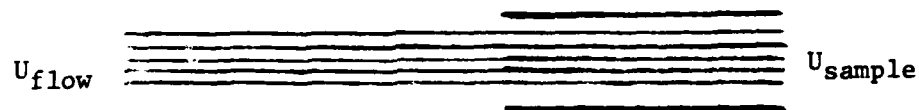
FIGURE 4

Pitot-Static Probe Modification

A. Superisokinetic sampling; $U_{\text{sample}} > U_{\text{flow}}$



B. Isokinetic sampling; $U_{\text{sample}} = U_{\text{flow}}$



C. Subisokinetic sampling; $U_{\text{sample}} < U_{\text{flow}}$



FIGURE 5

Qualitative Effect of Isokinetic Sampling

An iterative procedure had to be used to sample the jet isokinetically due to the dependence of sample concentration on sample velocity (4,5). Equations (1), (2), and (3) below demonstrate this dependence.

$$MW = x_{CO_2} MW_{CO_2} + (1 - x_{CO_2}) MW_{air} \quad (1)$$

$$\rho = PMW/\bar{R}T \quad (2)$$

$$U = (2 \Delta P/\rho)^{1/2} \quad (3)$$

Where

MW = Molecular Weight

x = Mole Fraction

ρ = Density

P = Static Pressure

$\bar{R}$ = Universal Gas Constant

T = Temperature

U = Axial Velocity

ΔP = Total-Static Pressure

First, ΔP and T were measured. Next a sample of gas was taken at an arbitrary velocity and the molecular weight calculated from Equation (1). Then the density and velocity were computed using Equations (2) and (3), the Ideal Gas equation of state and Bernoulli's Equation for low speed flow, respectively. The velocity calculated from Equation (3) was then used as the new velocity for the next sample and the whole procedure repeated until the sample velocity and the flow velocity were equal. Usually only two iterations were required.

Gas Analysis

Gas samples were analyzed according to the concentration of CO_2 : for mole fractions less than 0.30, CO_2 was measured directly with an infrared analyzer; when mole fractions exceeded 0.30, the concentration of oxygen was measured using a paramagnetic analyzer. The concentration of O_2 was used to calculate CO_2 concentrations because it was assumed that only CO_2 , O_2 , and N_2 were present in the sample with the sum of their mole fractions equal to unity and mole ratio of N_2/O_2 3.76.

Summary of Operating Conditions

Four different experiments were conducted to isolate the effects of jet density and confinement on the spreading and entrainment rates of the CO_2 jet. The CO_2 jet was heated until its density was the same as that of the surrounding air according to the following relationship:

$$\begin{aligned} p_{\text{CO}_2} &= p_{\text{air}} \\ (\text{PMW}/\bar{RT})_{\text{CO}_2} &= (\text{PMW}/\bar{RT})_{\text{air}} \\ (T_{\text{CO}_2}/T_{\text{air}}) &= (\text{MW}_{\text{CO}_2}/\text{MW}_{\text{air}}) = 1.52 \end{aligned}$$

Here it was assumed that the static pressure of the jet after leaving the nozzle was equal to ambient pressure. A summary of the operating conditions is shown in Table 1.

For each test case listed in Table 1, radial measurements of velocity, CO_2 concentration, and temperature were made in each of the three main regions of the jet: initial, transition, and fully developed as shown in Figure 6. The axial location for each radial profile is shown in Table 2.

TABLE 1

Summary of Operating Conditions

Test No.	CO ₂ mass flow(kg/Hr)	Air mass flow(kg/hr)	Jet Velocity (m/s)	Reynolds* No. X 10 ⁻³	Temp (K)	Description
1	6	0	88	22	450	Heated free jet
2	6	0	56	31	295	Isothermal free jet
3	6	252+*	87	22	450	Heated confined jet
4+	6	252+*	56	313	297	Isothermal confined jet

* Reynolds number based on jet diameter and inlet conditions.

+ Previous study conducted in same facility by Lightman and Roquemore (1).

+* Air mass flow corresponds to an average velocity of 1 and was used to prevent CO₂ from building up in the tunnel.

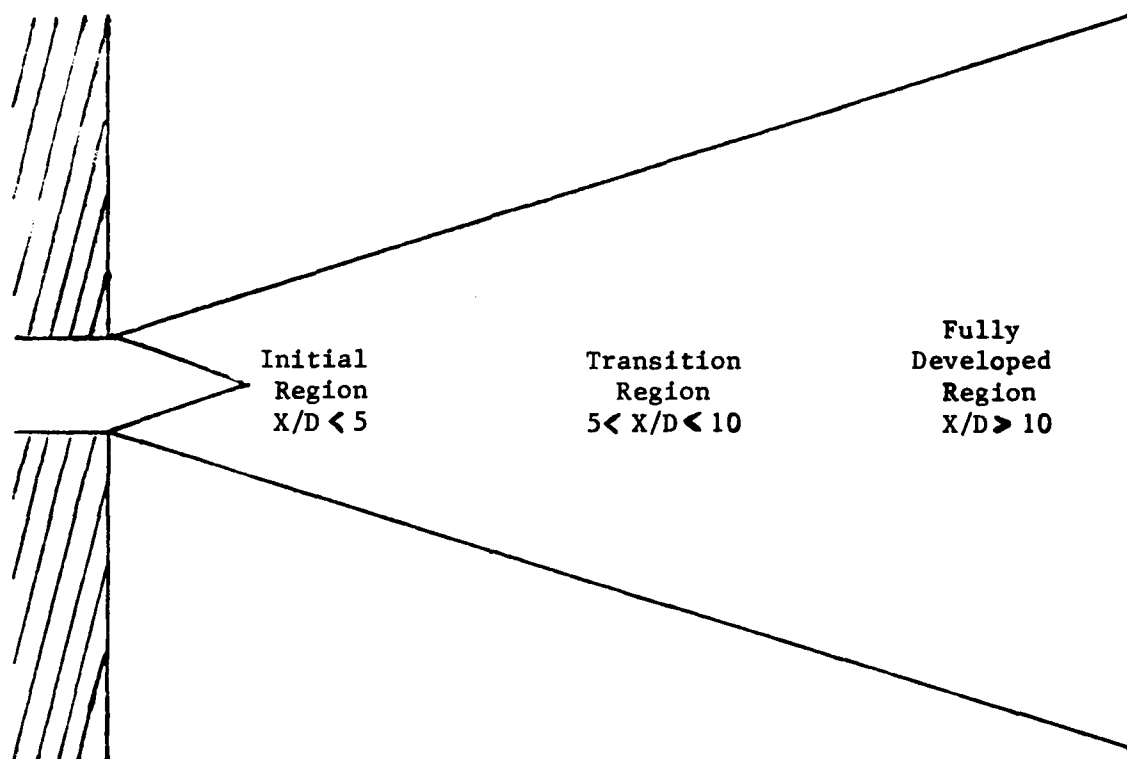


FIGURE 6

Three Main Regions of a Turbulent Jet

TABLE 2

AXIAL LOCATION OF RADIAL PROFILES				
Axial Distance CM; (X/D)	Test No. 1 Heated Free Jet	Test No. 2 Isothermal Free Jet	Test No. 3 Heated Confined Jet	Test No. 4 Isothermal Confined Jet
.05 (.105)	X	X	X	X
.5 (1.05)	X	X	X	X
1 (2.09)	X	X	X	X
2 (4.19)			X	
3 (6.28)	X	X	X	X
4 (8.38)			X	
5 (10.47)	X	X	X	X
6 (12.57)			X	
8 (16.75)	X	X	X	X
10 (20.94)	X	X	X	X
14 (29.32)	X	X	X	X
18 (37.70)	X	X	X	X

III. Results And Discussion

Effect of Isokinetic Sampling

CO₂ concentrations were greatly affected by the rate of sample extraction for axial distance less than 5 cm (10.47 X/D) where large velocity and concentration gradients exist (4,5). Up to a 20% difference in CO₂ concentration is possible when sampling isokinetically versus superisokinetically. This result is shown in Figure 7 for an axial location of 0.5 cm (1.05 X/D). The isokinetic profile is flatter in the central region and has a greater slope in the shear layer. This is because the superisokinetic sampling method has a larger sample capture area and draws air in from outside the jet which reduces the measured CO₂ concentration.

Velocity Increase Near Jet Exit

An interesting velocity profile occurs near the jet exit caused by the difference in density between the jet and the surrounding air as well as the presence of the bluffbody. Figures 8, 9, 10, and 11 illustrate this phenomenon for the heated free jet, isothermal free jet, heated confined jet, and isothermal confined jet, respectively at an axial distance of 0.05 cm (0.105 X/D).

In the heated jet studies the densities of the jet and the surrounding air were equal and the velocity was influenced only slightly as shown in Figures 8 and 10. However, in the isothermal jet studies, Figures 9 and 11, where the density of the CO₂ jet was 1.5 times the density of the surrounding air, the velocity at the edge of the jet shear layer is actually higher than the central jet itself. Analysis of

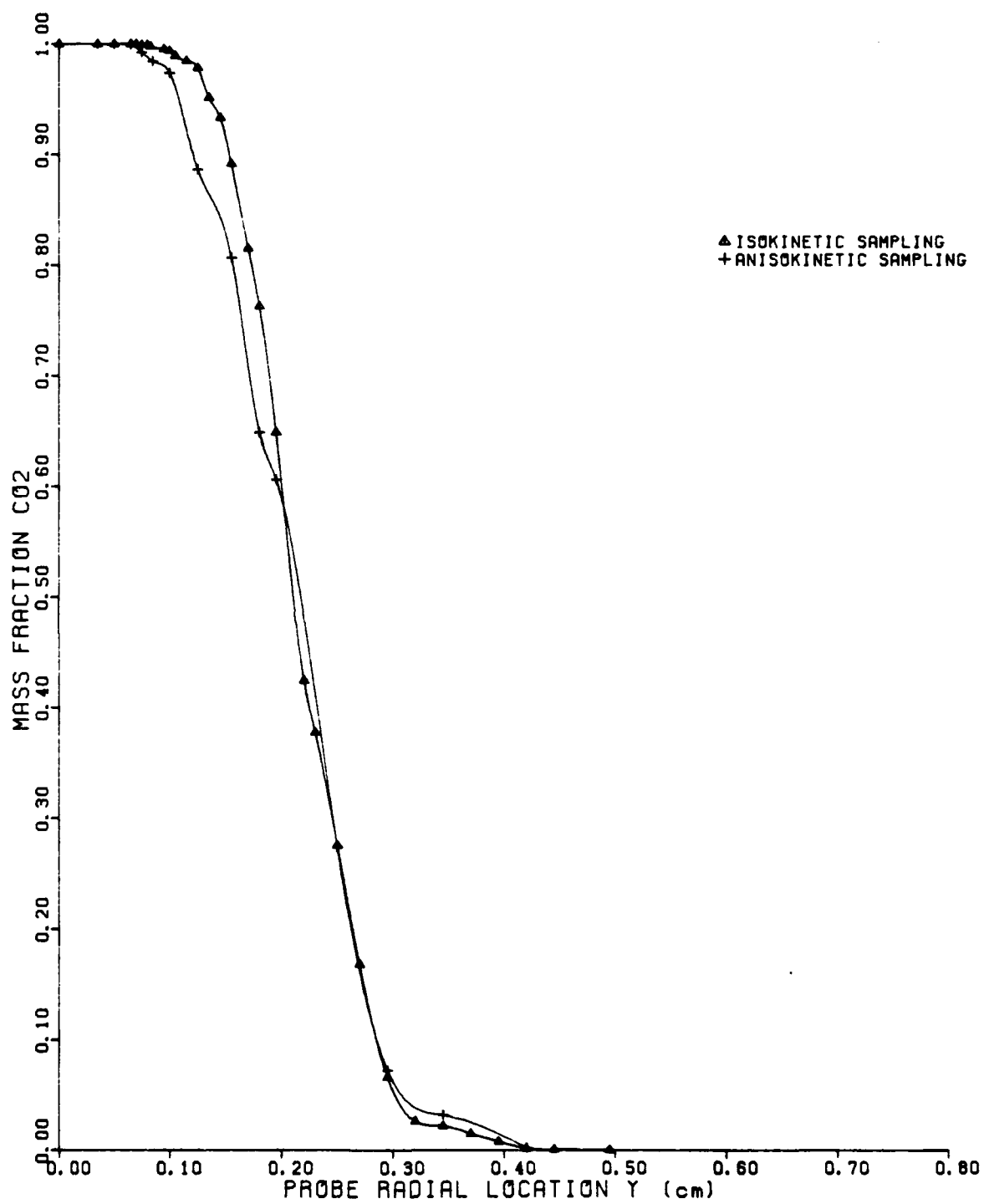


FIGURE 7

CO₂ Profile, Isokinetic Versus Anisokinetic X/D = 1.05

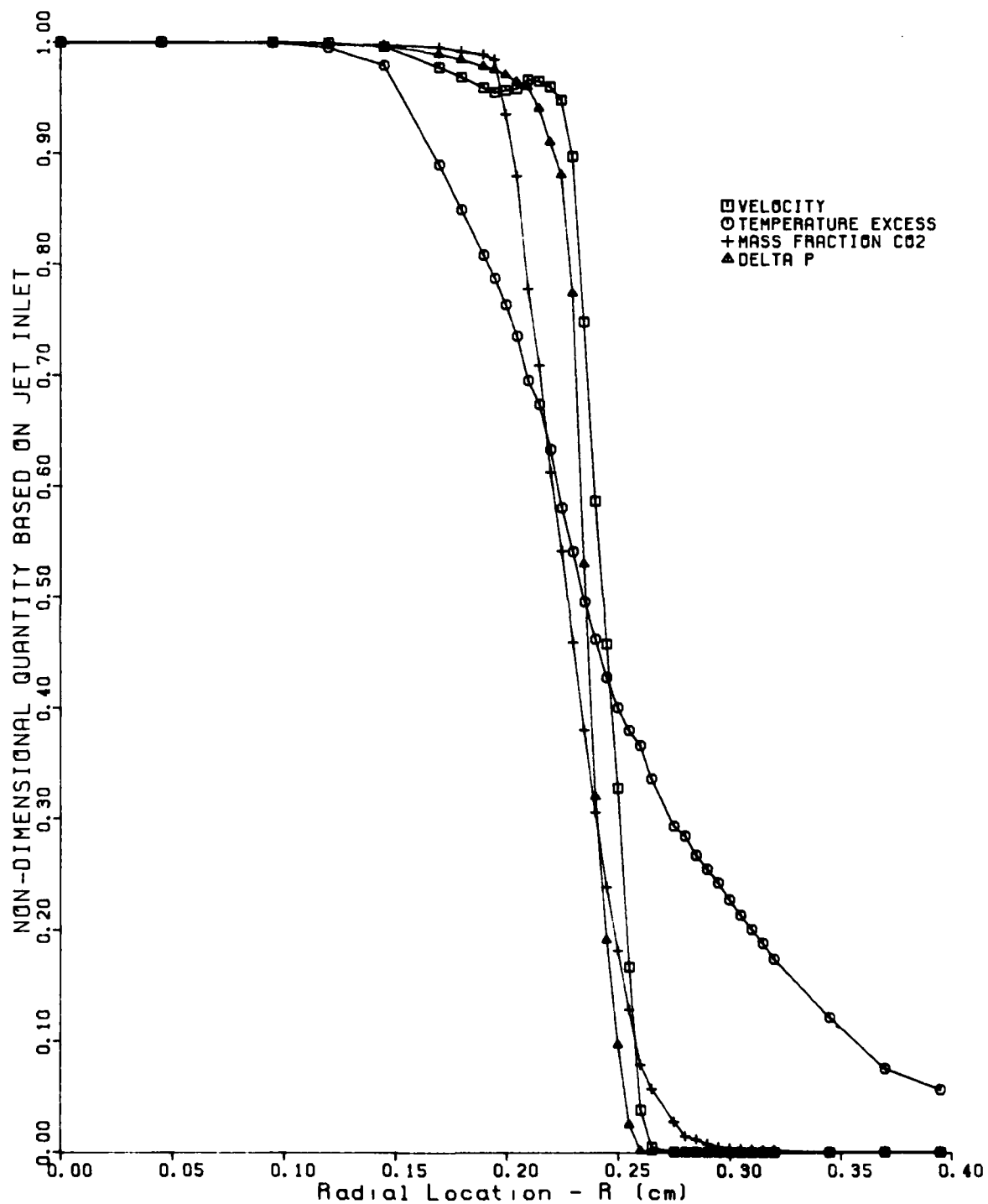


FIGURE 8

Velocity Increase, Heated Free Jet $X/D = 0.105$

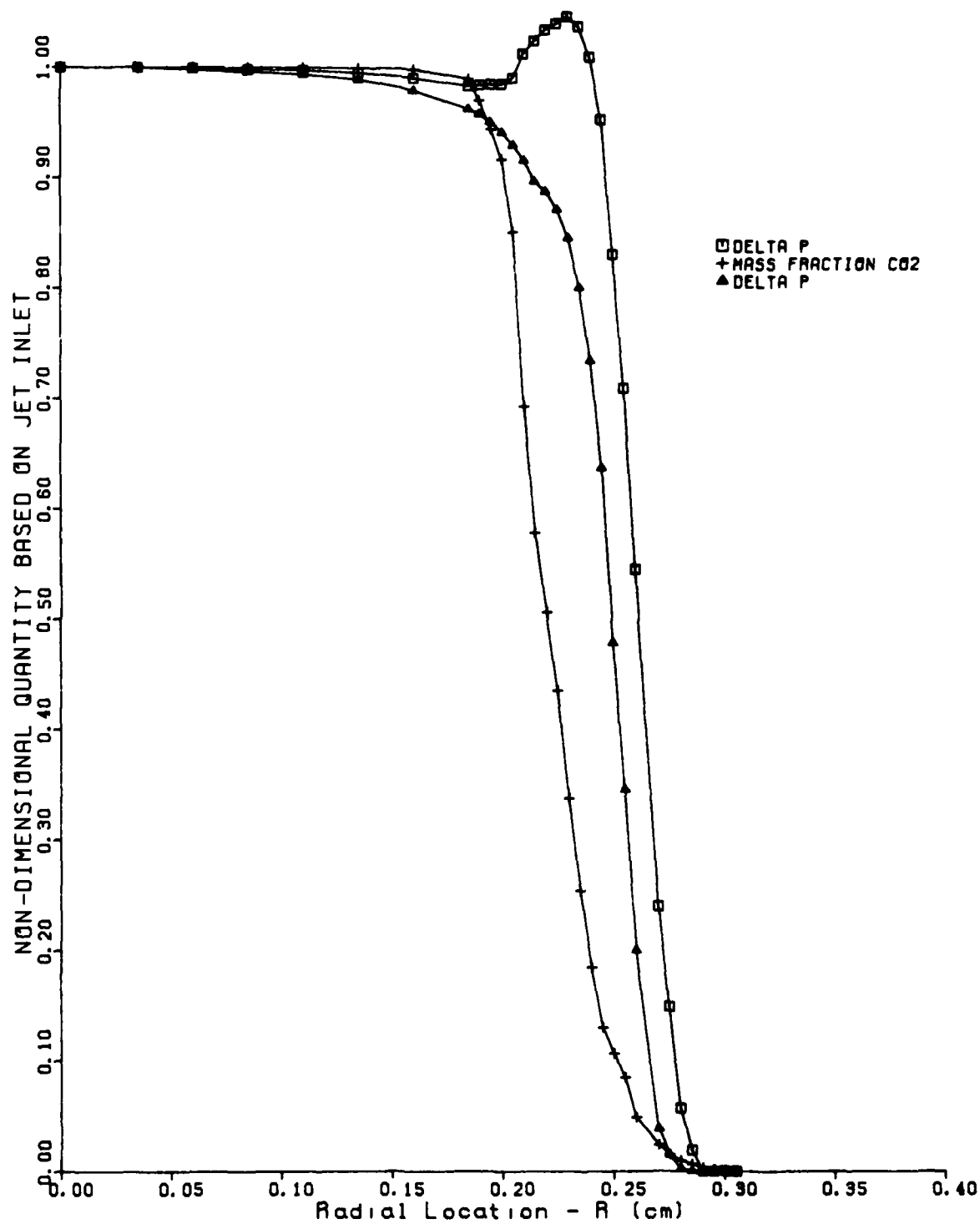


FIGURE 9

Velocity Increase, Isothermal Free Jet $X/D = 0.105$

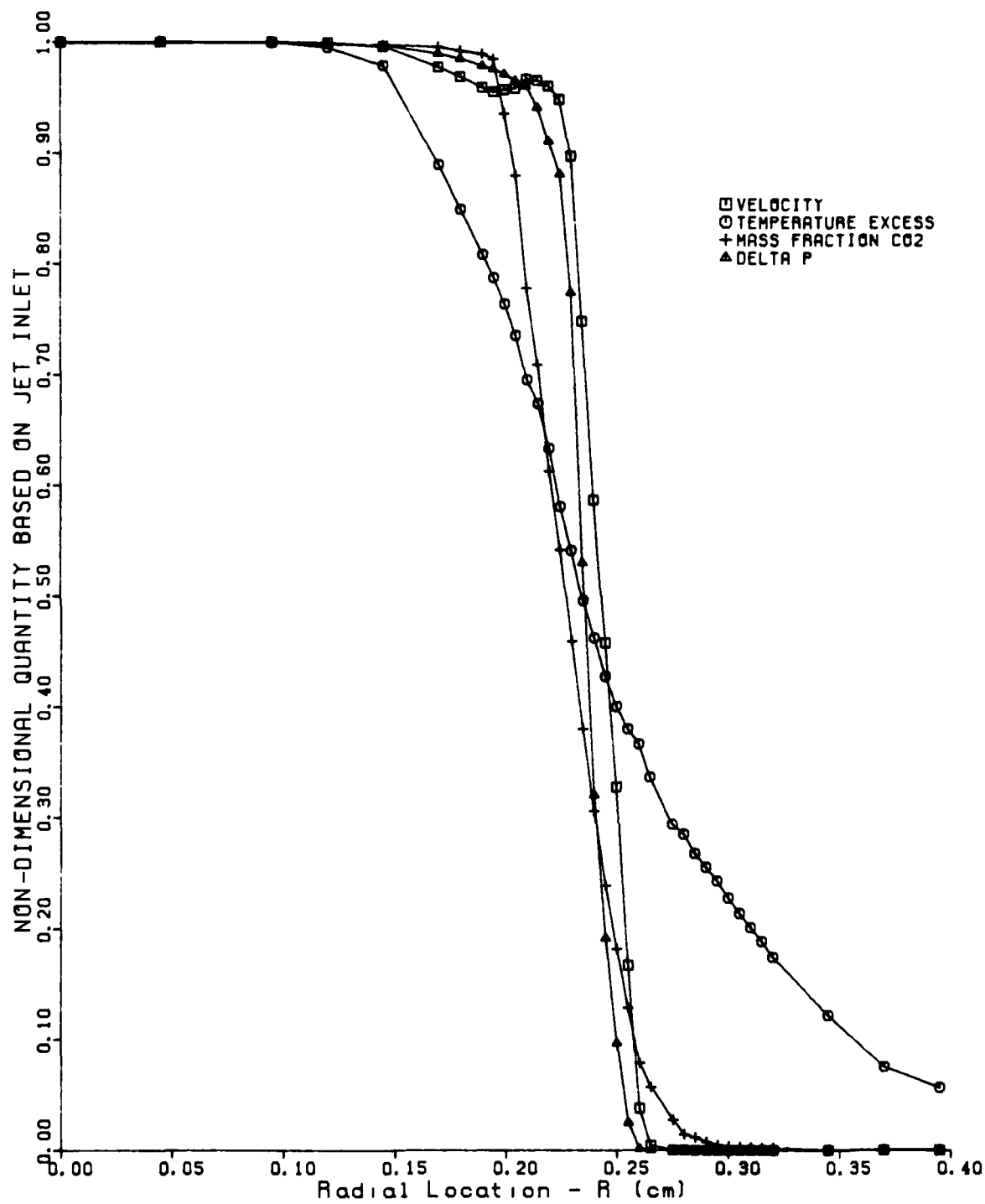


FIGURE 10

Velocity Increase, Heated Confined Jet $X/D = 0.105$

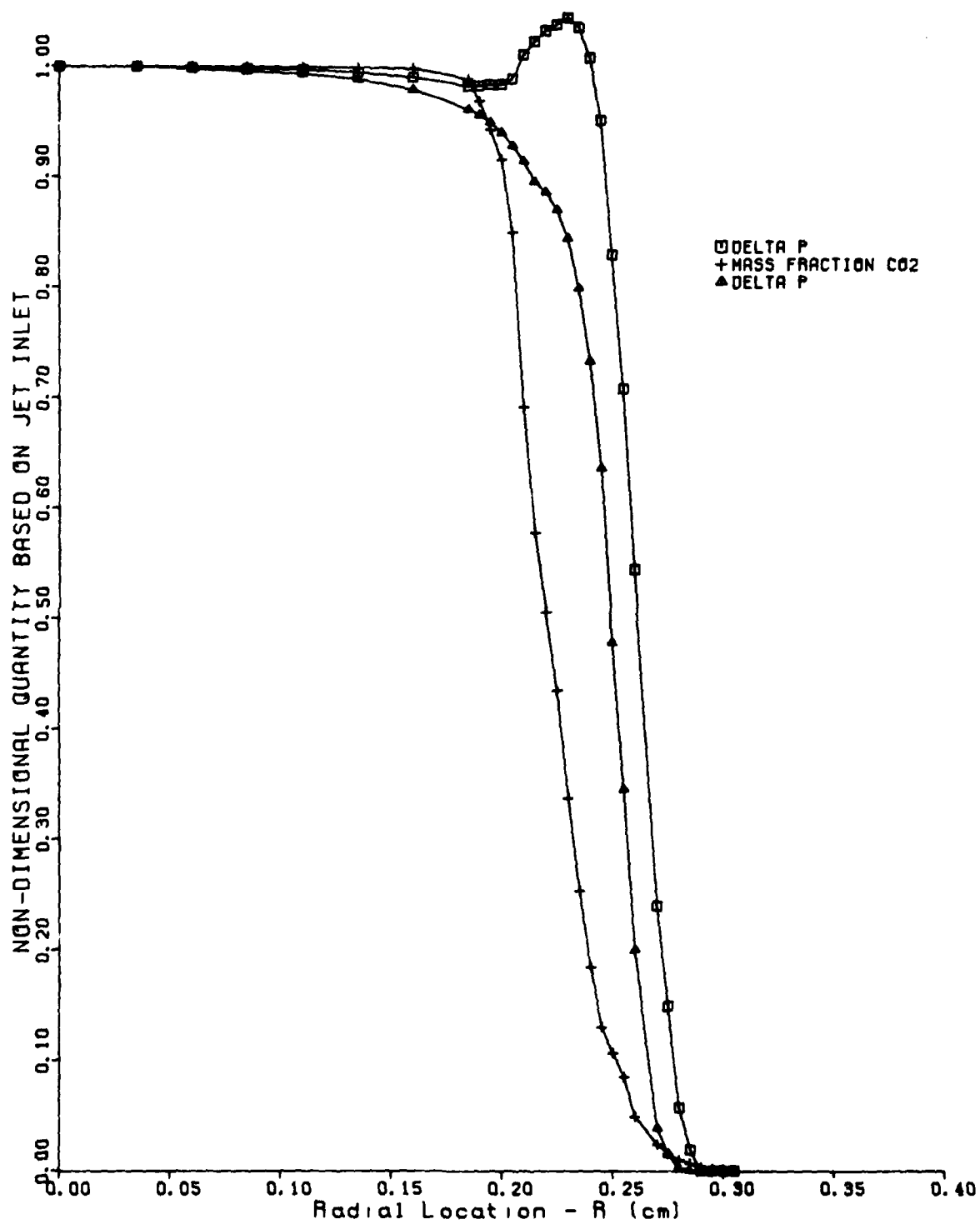


FIGURE 11

Velocity Increase, Isothermal Confined Jet $X/D = 0.105$

the individual components that influence the velocity provides insight into this change in velocity.

$$U = (2 \Delta P / \rho)^{1/2}$$

Using the Ideal Gas Law, $\rho = PMW/\bar{R}T$

$$U = (2\bar{R}/P)^{1/2} (\Delta PT/MW)^{1/2} \quad (4)$$

Equation(4), together with Figures 9 and 11, illustrate this phenomenon very clearly. At an axial location of 0.05 cm (0.105 X 1D) very little mixing has occurred, as evidenced by the very flat CO₂ concentration profiles shown in Figures 8-11. This lack of mixing results in a very thin boundary layer and an almost abrupt density change from the CO₂ jet to the surrounding air. The velocity profiles in Figures 8-11 are believed to be influenced by this density difference. Both incompressible and compressible flow theory led to the same calculated velocities.

The actual cause of the velocity increase in the shear layer near the jet exit is not known but it is possible that the bluff body influences this velocity increase. The shearing action of the jet accelerates and entrains the air near the edge of the jet. The bluff body resists this radial inflow of air into the jet causing a thin boundary layer to form on the bluff body and a decrease in pressure. This lower pressure influences the CO₂ jet while it is still inside the nozzle as well as slightly downstream (X/D less than 0.5) because pressure waves travel at the speed of sound and the jet is subsonic (Mach number = 0.2 to 0.3 at the exit plane). The favorable longitudinal pressure gradient in this region of the jet accelerates the entraining

air to a higher velocity than the CO_2 jet because the air is much lighter than CO_2 . It is also possible that the probe itself causes the velocity increase shown in Figures 8-11 due to flow blockage.

Spreading Rate of Jet

Spreading rate of the jet was determined using the half width at half maximum criterion as shown in Figure 12. All four test cases were normalized by their exit conditions in order to compare their spreading rates. The half widths were calculated for velocity, temperature, and CO_2 concentration and are summarized in Table 3.

Relative Spreading Rates for Velocity, Temperature, and Mass

The relative spreading rate of velocity, temperature and CO_2 concentration is a measure of the radial transport of momentum, energy, and mass, respectively. In each region of the jet (initial, transition, and fully developed) the rate at which velocity spreads relative to the scalars of temperature and CO_2 is different.

The velocity half width in the initial region of the jet (0 to 5 jet diameters) is greater than the half widths for temperature or CO_2 as seen in Figure 13. This is due to the velocity increase already discussed and shown in Figures 8 through 11. Also, the temperature profiles near the jet face for the heated studies are not as flat as the CO_2 profiles because of heat loss through the nozzle wall. The minor irregularities in the velocity and temperature profiles at the jet exit are absent by the end of the initial region.

In the developing region of the jet (5 to 10 jet diameters) the velocity, temperature, and CO_2 concentration spread at very nearly the same rate as can be seen in Figure 13. Similar results have been determined by other researchers although the location varied from 5 to 9 jet diameters (6,7).

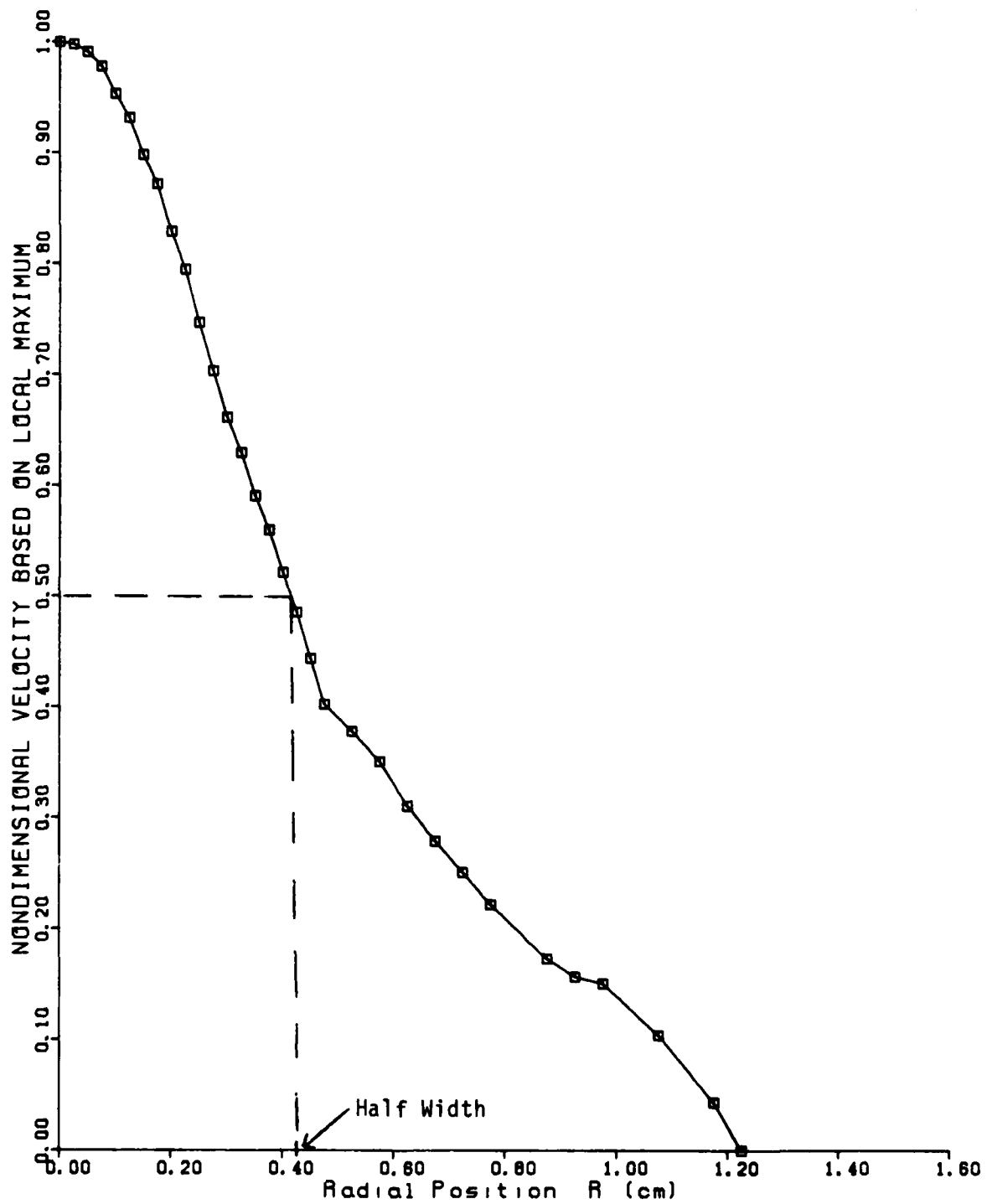


FIGURE 12

Half Width Principle

TABLE 3

Half Widths For Velocity, Temperature, CO ₂ Concentration (CM)										
AXIAL DISTANCE CM; (X/D)	TEST NO 1 HEATED FREE JET		TEST NO 2 ISOTHERMAL FREE JET		TEST NO 3 HEATED CONFINED JET		TEST NO 4 ISOTHERMAL CONFINED JET			
	U	T	CO ₂	U	CO ₂	U	T	CO ₂	U	CO ₂
.05 (.105)	.248	.235	.231	.261	.227	.225	.198	.231	.25	.232
.5 (1.05)	.291	.241	.238	.297	.245	.289	.214	.238	.285	.241
1 (2.09)	.308	.245	.242	.324	.270	.295	.259	.261	.312	.256
3 (6.28)	.415	.431	.415	.494	.490	.357	.385	.35	.375	.362
5 (10.47)	.661	.605	.615	.719	.784	.476	.520	.519	.485	.505
8 (16.75)	.914	1.040	1.029	1.210	1.201	.740	.950	.921	--	--
10 (20.94)	1.241	1.401	1.402	1.499	1.585	.971	1.241	1.151	1.050	1.181
14 (29.32)	1.823	2.010	1.983	1.956	2.194	1.291	1.401	1.460	1.213	1.320
18 (37.70)	2.222	2.689	2.716	3.048	3.105	2.151	2.172	2.16	2.071	2.152

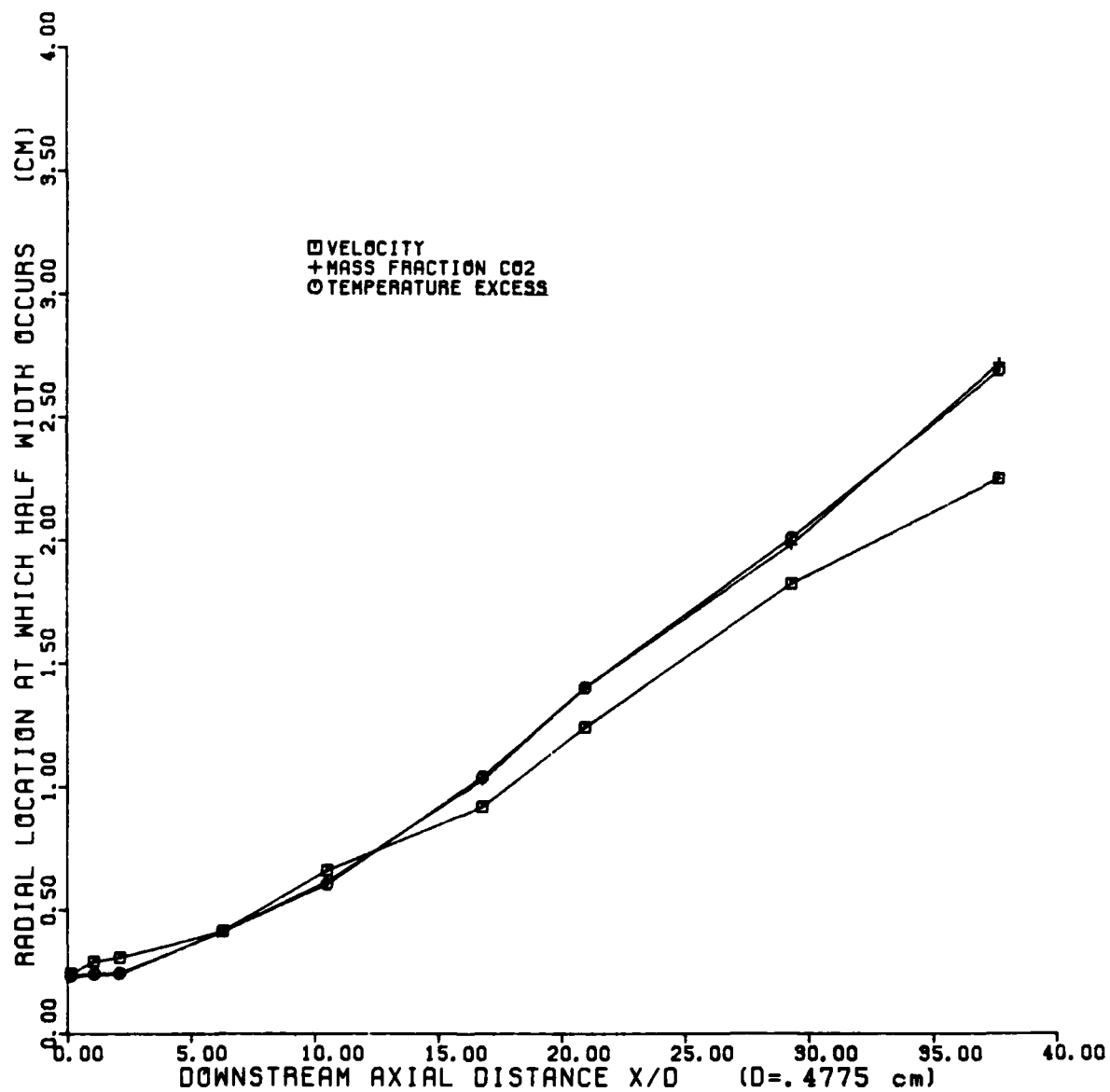


FIGURE 13

Relative Spread of Velocity, CO₂, Temperature

The fully developed region of the jet (greater than 10 jet diameters) was characterized by temperature and CO_2 concentration spreading faster than velocity. Lightman and Roquemore (1) used laser doppler anemometry (LDA) to measure turbulence intensity and average velocity. Their results indicate that the outer region of the jet is much less turbulent than the central region of the jet for X/D greater than 10. This means that the relative importance of molecular diffusion to turbulent transport increases as the distance from jet centerline increases.

The molecular Prandtl Number (ratio of momentum to thermal energy diffusivity) for the mixture at the outer region of the jet is about 0.7 indicating that if the transport process is influenced by diffusion (even though it is controlled by turbulence) that energy should be transported faster than momentum.

All previous research work examined also found that temperature spread faster than momentum in the fully developed region of the jet (6, 8-14). Also, within experimental error, temperature and concentration spread at the same rate in all regions of the jet. This has also been found by other researchers (6,7) and is shown in Figure 13.

Spread of Heated Versus Isothermal Jet

The isothermal jet spread faster than the heated jet as shown in Figure 14. Normally a heated jet spreads faster than an isothermal jet because the molecular and eddy diffusivities both increase with temperature (6, 10, 13). However, the large velocity increase (56 m/s to 87 m/s) due to heating the jet while maintaining mass flow constant changed the nature of the heated jet such that similar flow conditions did not exist in the two jets. This change in the character of the jets was studied qualitatively through flow visualization.

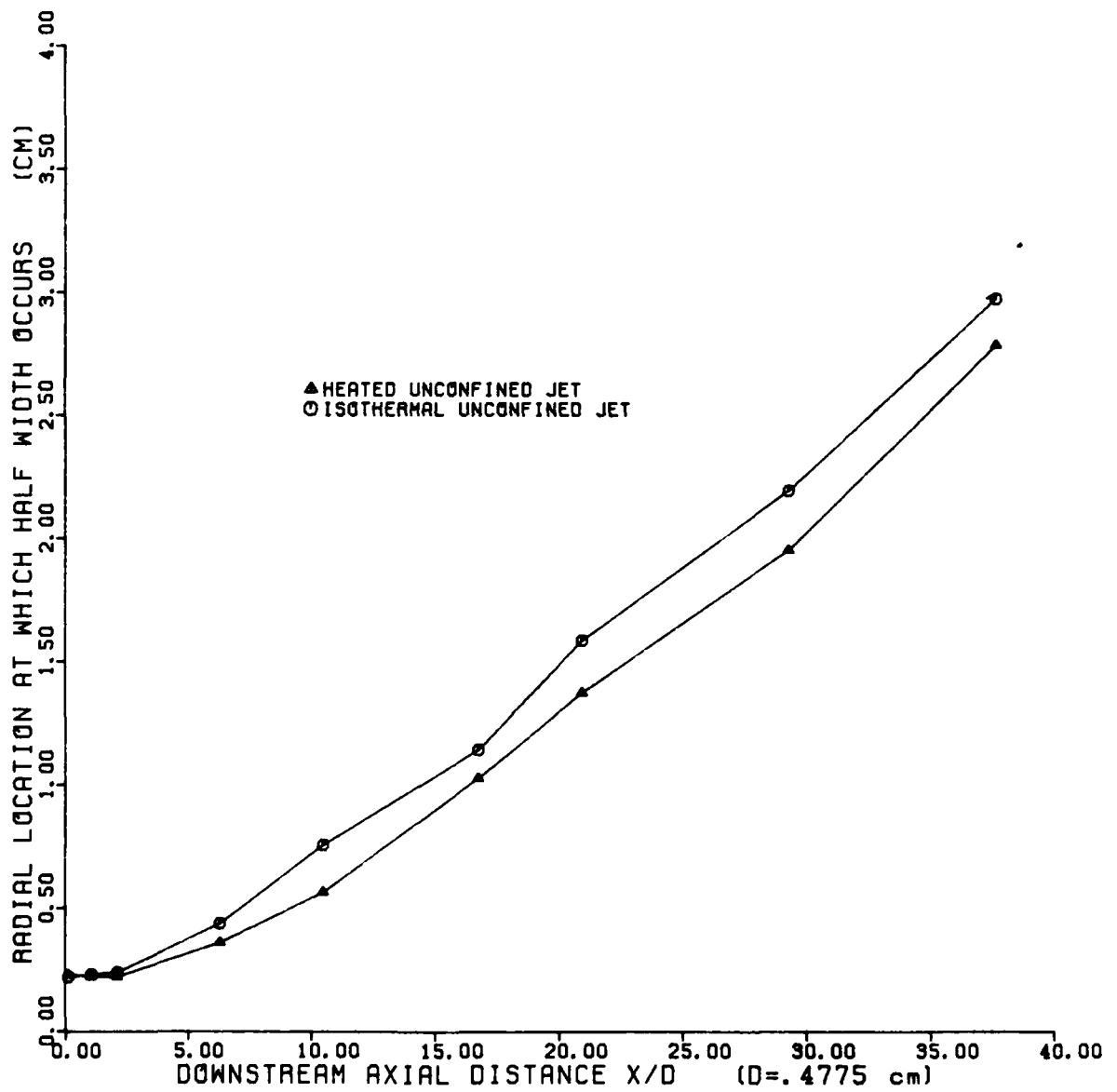


FIGURE 14

Relative Spread of Heated and Isothermal Jets

Spread of Confined Versus Free Jet

The free jets expanded faster than the confined jet for both heated and isothermal jets as shown for the isothermal studies in Figure 15. This result is due to the combined effects of a mild pressure gradient in the confinement as well as the influence of forced air flow in the annulus of the combustion tunnel, see Figure 1.

It is also interesting that the isothermal and heated confined jets, at distances greater than 10 jet diameters, spread at about the same rate. This is an indication that the confinement plays a more important role in jet spreading than does the initial condition of the jet.

Entrainment of Air

The amount of air entrained by the jet was determined by combining the time-average radial profiles of density, velocity, and mass fraction CO_2 . The number of radial points in each profile justified assuming a linear relationship between points for the numerical integration scheme.

$$m_{\text{CO}_2}(x) = 2\pi \int_0^{\infty} \rho(r,x)U(r,x)f_{\text{CO}_2}(r,x)rdr \quad (5)$$

$$m_{\text{total}}(x) = 2\pi \int_0^{\infty} \rho(r,x)U(r,x)rdr \quad (6)$$

$$m_{\text{air}}(x) = m_{\text{total}}(x) - m_{\text{CO}_2}(x)$$

where

ρ = density of mixture

U = axial velocity

f_{CO_2} = mass fraction CO_2

m = mass flow rate

r = radial distance

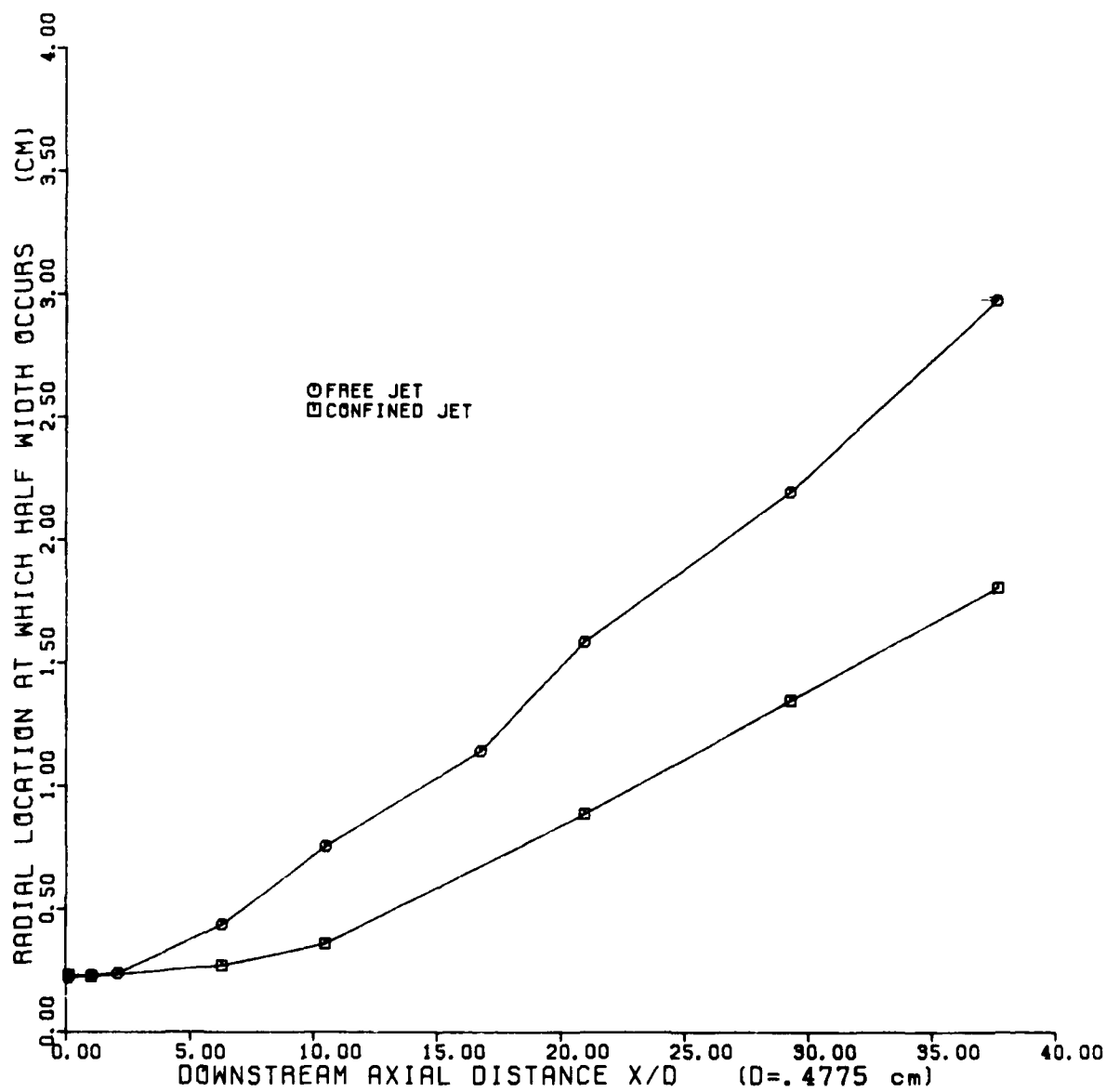


FIGURE 15

Relative Spread of Confined and Free Isothermal Jets

Equation (5) served as a check on the accuracy of the individual measurements because the mass flow rate of CO_2 at any axial position must be equal to the inlet mass flow rate of CO_2 .

Effect of Jet Density on Entrainment

The heated CO_2 jet (87 m/s) entrained more air than the isothermal jet (56 m/s) due to the higher velocity. This phenomenon is clearly evident in the free jet studies shown in Figure 16 where the hot jet entrains an average of 30% more air than the isothermal jet.

Effect of Confinement on Entrainment

A qualitative analysis would suggest that a confinement would restrict the radial inflow of air into the jet. This indeed was verified as seen in Figure 17, where the isothermal and heated confined jets entrain about the same amount of air in the fully developed turbulent region. Also, the free jets entrain from 30-60% more air than the confined jets at any given axial location.

Entrainment Growth Rate Characteristic

The entrainment growth characteristic, C_2 , is a parameter that identifies the increase in mass flow rate of the jet with axial distance. Ricou and Spalding (3) first identified C_2 and defined it as the following:

$$C_2 = \frac{d(\dot{m}_{\text{air}}/\dot{m}_0)}{d(X/D)} (\rho_0/\rho_s)^{1/2} \quad (7)$$

where

ρ_0 = initial jet density

ρ_s = density of surrounding medium

$\dot{m}_0$ = jet initial mass flow rate

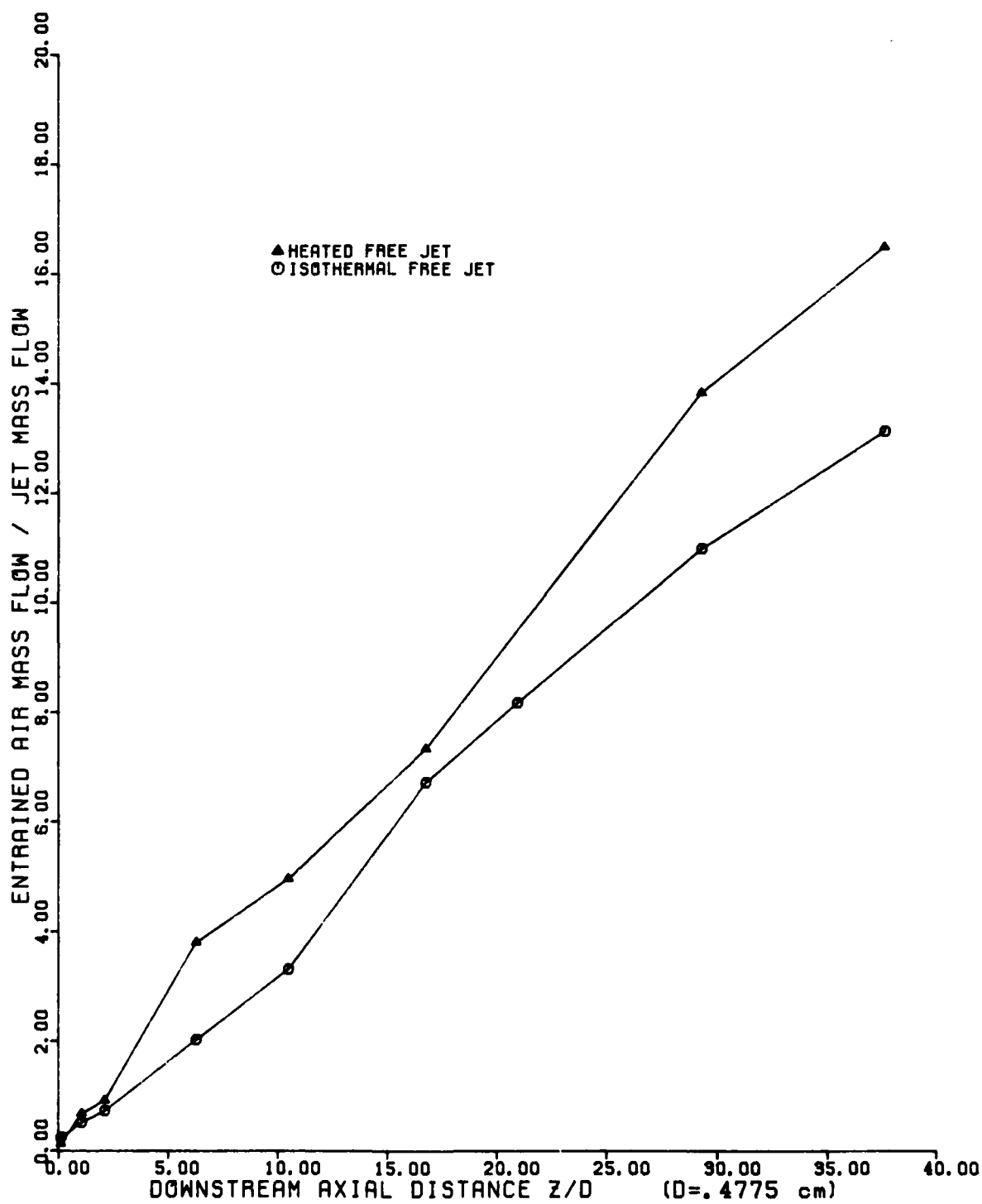


FIGURE 16

Entrainment for Heated and Isothermal Free Jets

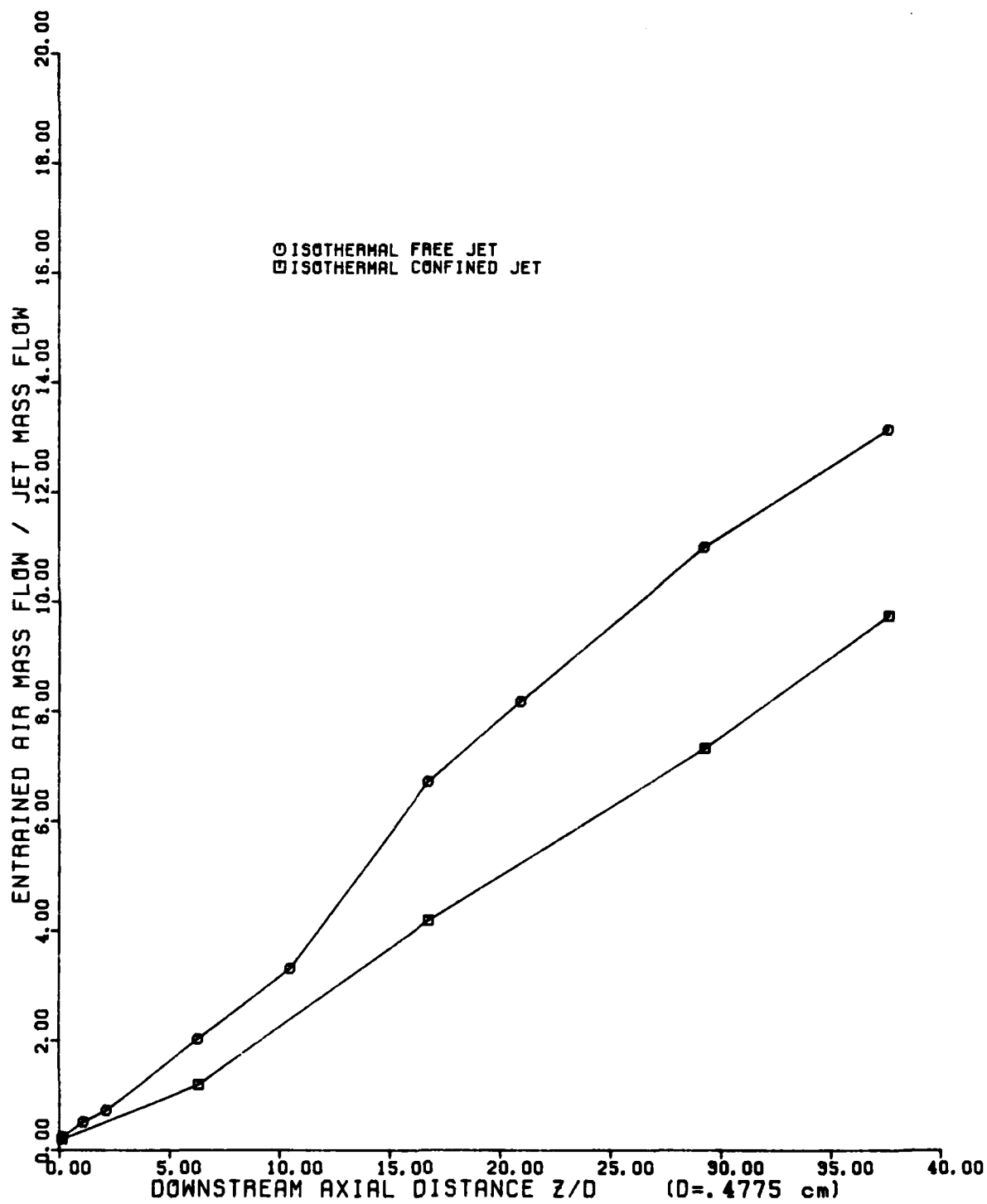


FIGURE 17

Entrainment for Confined and Free Isothermal Jets

C_2 was calculated for the fully developed regions of the jets using a least squares approximation to the data and the results are listed in Table 4. The best known estimate of C_2 is 0.32 recommended by Ricou and Spalding (3) and verified for the confined CO_2 jet studies. For the free jet studies, however, no agreement with other researchers was found.

Flow Visualization

The purpose of the flow visualization study was twofold:

1. Show that isothermal CO_2 jet spread faster than heated CO_2 jet.
2. Determine qualitative effect of jet velocity on spreading and entrainment characteristics.

The first objective was realized visually but the results are not presentable due to the poor quality of the photographs for the heated jet. It was determined that heating CO_2 had an effect on the light scattering and possibly the formation of the TiO_2 particles. However, the qualitative characteristics for the heated jet (87 m/s with mass flow 6 kg/hr) and the isothermal jet (87 m/s with mass flow 9 kg/hr) are the same. Therefore the pictures shown in Figures 19 and 21 are actually isothermal jets but may be thought of as heated jets for visual comparison.

Figures 18 and 19 are time average photographs (exposure time $\frac{1}{2}$ second) of the isothermal CO_2 jet with exit velocities of 56 and 87 m/s, respectively. The lower velocity jet does spread faster than the higher velocity jet as indicated from measurements of the spreading rate shown in Figure 14. The lower velocity jet has a visually distinctive transition region near $X/D = 10$ whereas the higher velocity jet's visual transition region occurs near $X/D = 5$.

TABLE 4

ENTRAINMENT GROWTH CHARACTERISTIC, C_2	
C_2	TEST NO.
.40	1, Heated Free Jet
.39	2, Isothermal Free Jet
.31	3, Heated Confined Jet
.32	4, Isothermal Confined Jet

All values of C_2 for $X/D > 15$

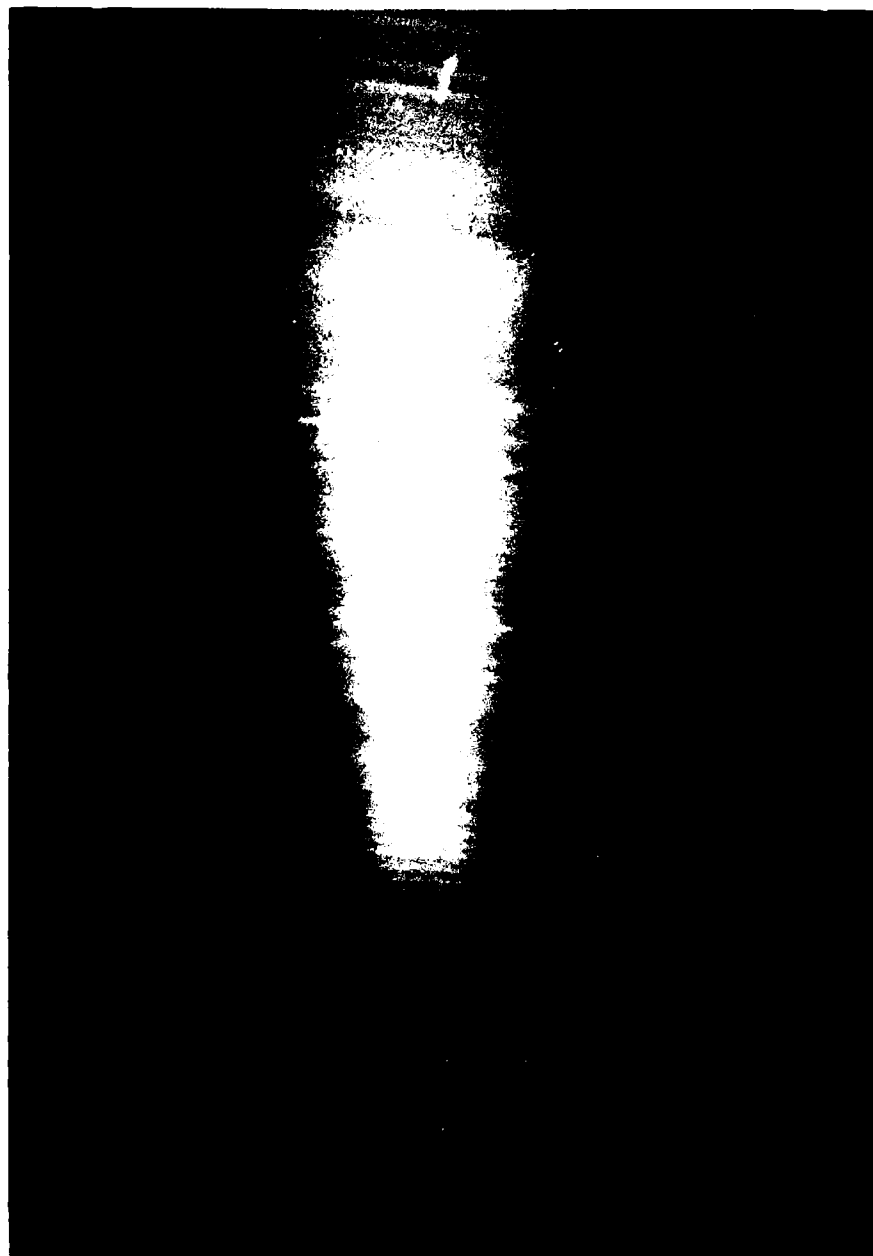


FIGURE 18

Flow Visualization, Isothermal Free Jet (56 m/s) Time AVERAGE

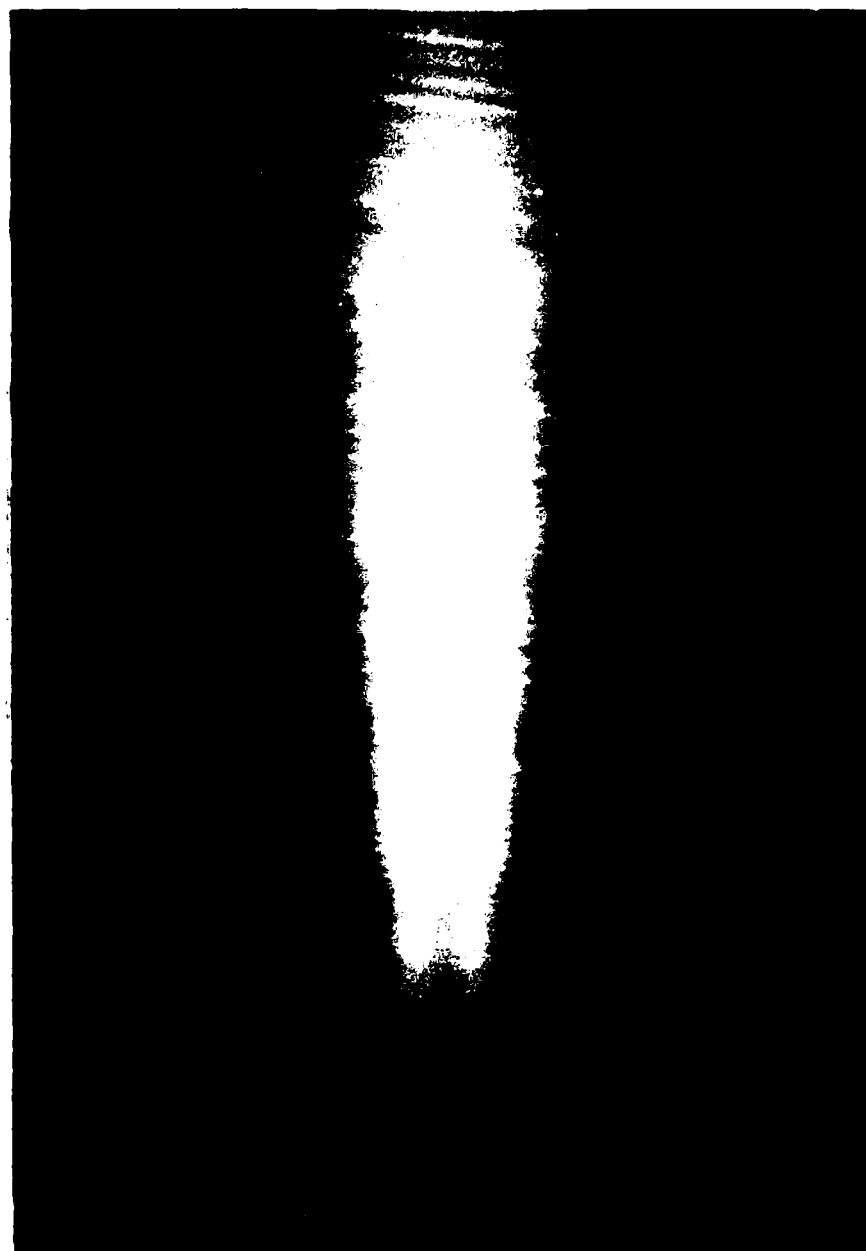


FIGURE 19
Flow Visualization, Heated Free Jet (87 m/s) Time Average

A better qualitative summary of the instantaneous nature of the jets is shown in Figures 20 and 21 for the low and high velocity jets, respectively. The structures at the periphery of the jet seem to be larger and penetrate to a greater radial distance in the lower velocity jet compared to the higher velocity jet. This might provide an explanation as to why the isothermal jet (56 m/s) spreads faster than the heated jet (87 m/s) shown in Figure 14. Also, the change in the entrainment rates shown in Figure 16 at axial locations of 10 and 5 X/D for the isothermal and heated jets, respectively, seem to coincide well with the visual transition region.

Curve Fits

The near-linear decrease of centerline jet velocity, temperature, and specie concentration, as well as the similar nature of radial profiles in the fully developed region of a turbulent jet, are well documented (8,9,10). Empirical equations that describe specific experiments are useful, but equations that apply to a universal class of experiments can be used to compare results of investigations by different researchers.

A suggested equation that fits the data of this investigation fairly well and relates to other investigators' work is a combination of curves suggested by Pai and Gortler. The centerline velocity decay recommended by Pai (10) is:

2-4

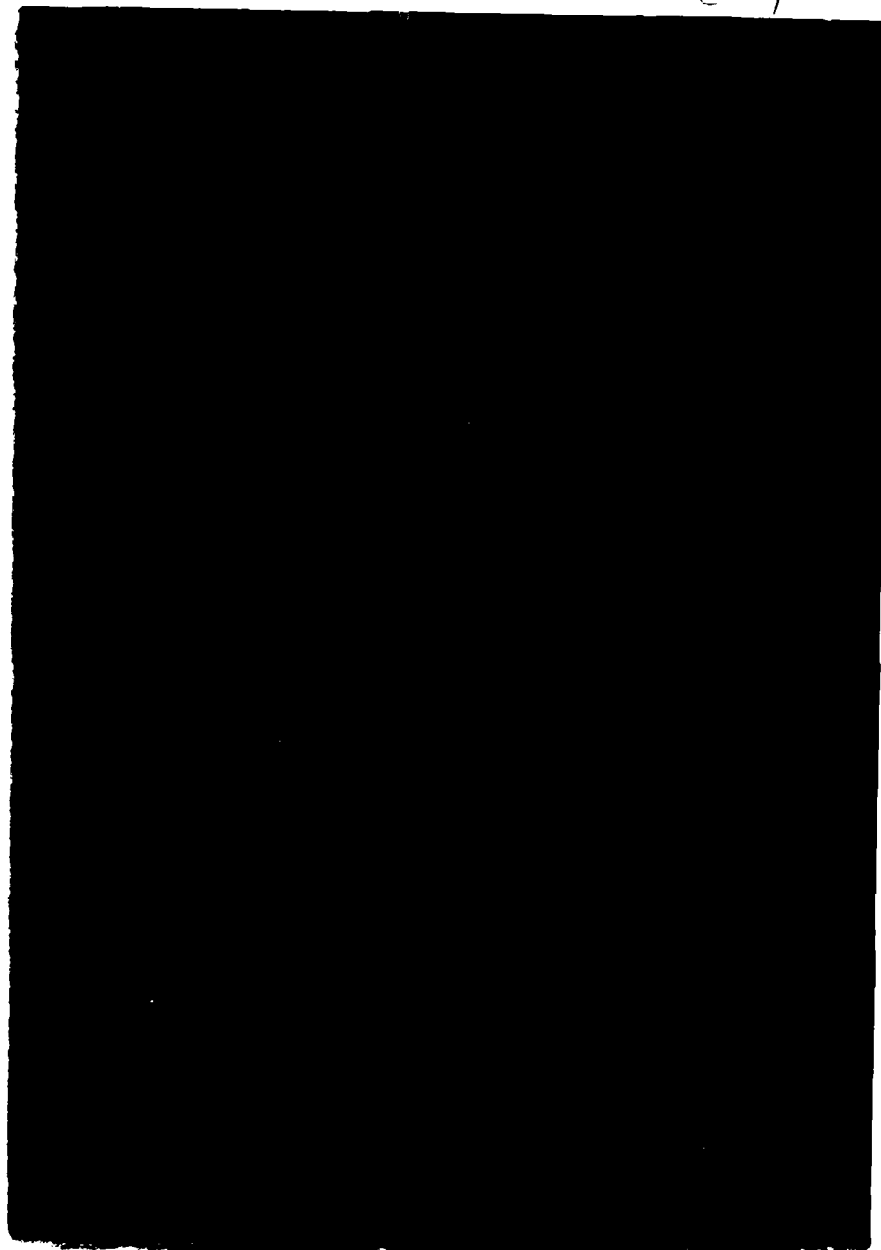


FIGURE 20

Flow Visualization, Isothermal Free Jet (56 m/s) Instantaneous

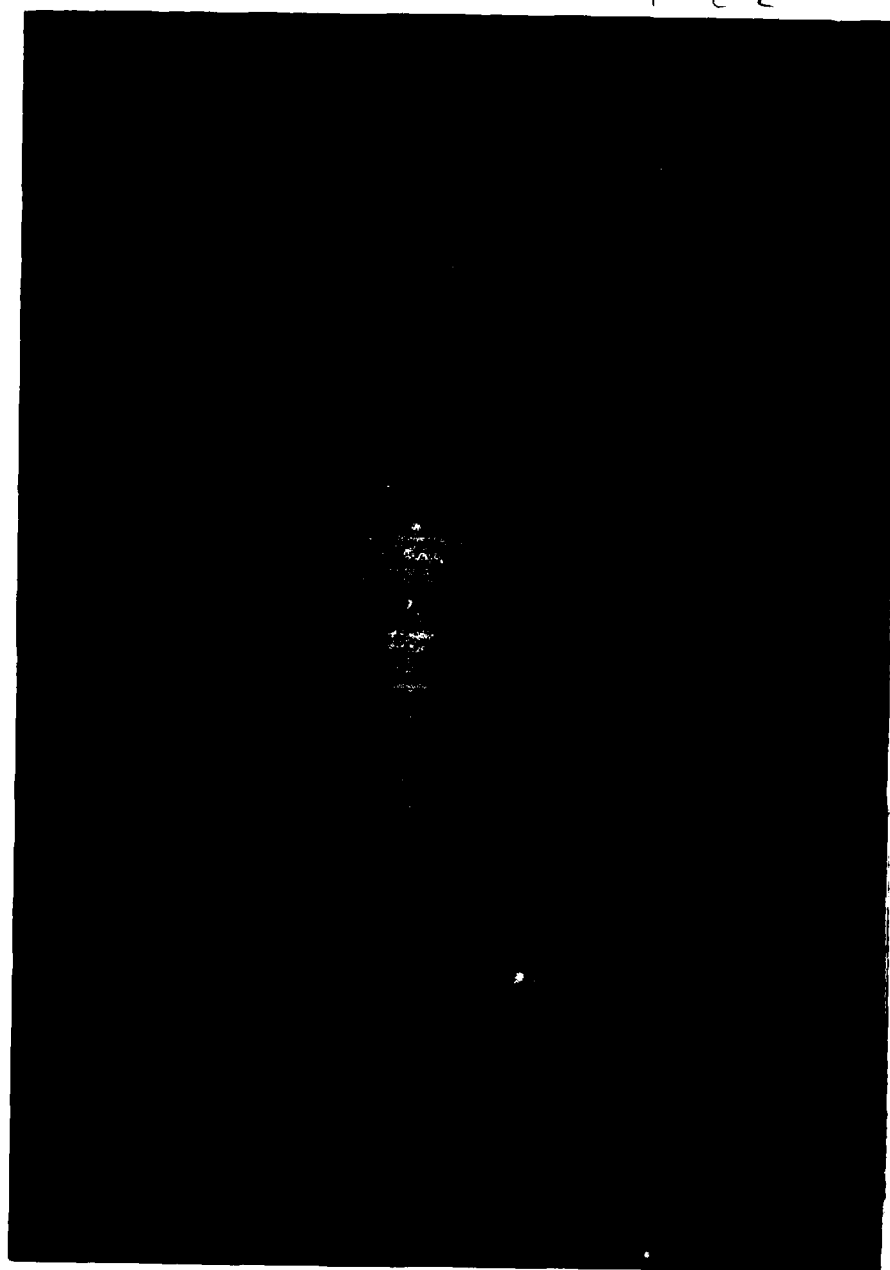


FIGURE 21
Flow Visualization, Heated Free Jet (87 m/s) Instantaneous

$$U_{\max}(0,X) = U_0 \left(1 - \exp\left(\frac{-A}{(X+a)/D}\right)\right) \quad (8)$$

where

- A = centerline velocity decay parameter
- a = location of virtual origin relative to nozzle exit
- X = axial distance from nozzle
- D = jet diameter
- U_0 = inlet velocity
- $U_{\max}$ = centerline velocity

Also, geometric similarity of velocity profiles in the fully developed region of the jet (greater than 10 X/D) is well represented by complementary error functions as described by Gortler (11).

$$U(r,X) = U_{\max}(1 - \text{erf}(\xi)) \quad (9)$$

where

- $\xi = r/X$, similarity variable
- a = constant that relates velocity profiles
- r = radial distance
- X = Axial distance

By combining Equations (8) and (9), an equation describing the fully developed flow field on a time averaged basis is achieved.

$$U(r,X) = U_0 \left(1 - \exp\left(\frac{-A}{(X+a)/D}\right)\right) (1 - \text{erf}(\xi)) \quad (10)$$

The apparent, or virtual, origin of the jet (a) was estimated from the half width of the jet using a least squares curve fit of the data. Figure 22 illustrates this procedure for the isothermal free jet. The centerline velocity decay parameter (A) was then determined from Equation (8) using Figure 23. The similarity constant (σ) was found using Equation (9) and tabulated values of the error function. The results for these constants are listed in Table 5.

The value of A determined by Pai for free air jets is 6.5 (10:120), the same value for the confined CO_2 jets is this study. However, for the free CO_2 jet studies, the value of A was 4.8, indicating that the centerline velocity decay is faster for the free jet than the confined jet.

The values of σ for this investigation using CO_2 into air jets ranged from 10.5 to 11.5, compared to 11 from Gortler (11) and 15 from Reichardt (14) using air into air jets. The fairly constant value of σ in this study indicates that the velocity profile in the fully developed region of the jet are geometrically similar as shown in Figure 24.

A typical curve predicted by Equation (10) is compared to actual data in Figures 25 and 26 for the free isothermal CO_2 jet at axial locations of 5 and 10 cm (10.5 and 20.9 X/D), respectively. Radial profiles coincide very well with the equations for R greater than 0.5 cm. For R less than 0.5 cm, the equation underpredicts the velocity by about 5%.

Summary of Results

Jet density and confinement both have qualitative and quantitative effects on the spreading and entrainment rates of a jet. A summary of the important results in this investigation are:

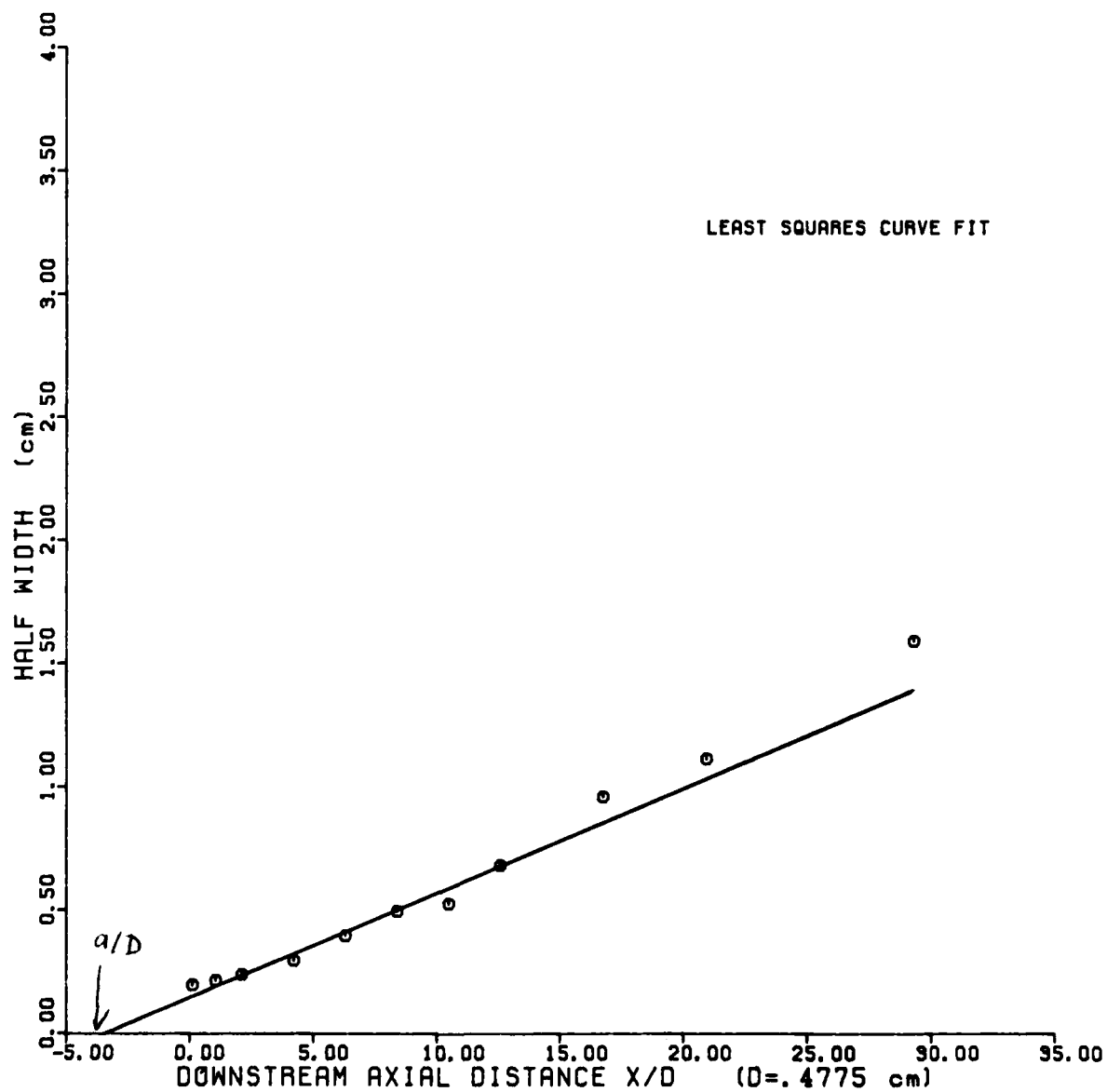


FIGURE 22

Determination of Virtual Origin, Isothermal Free Jet

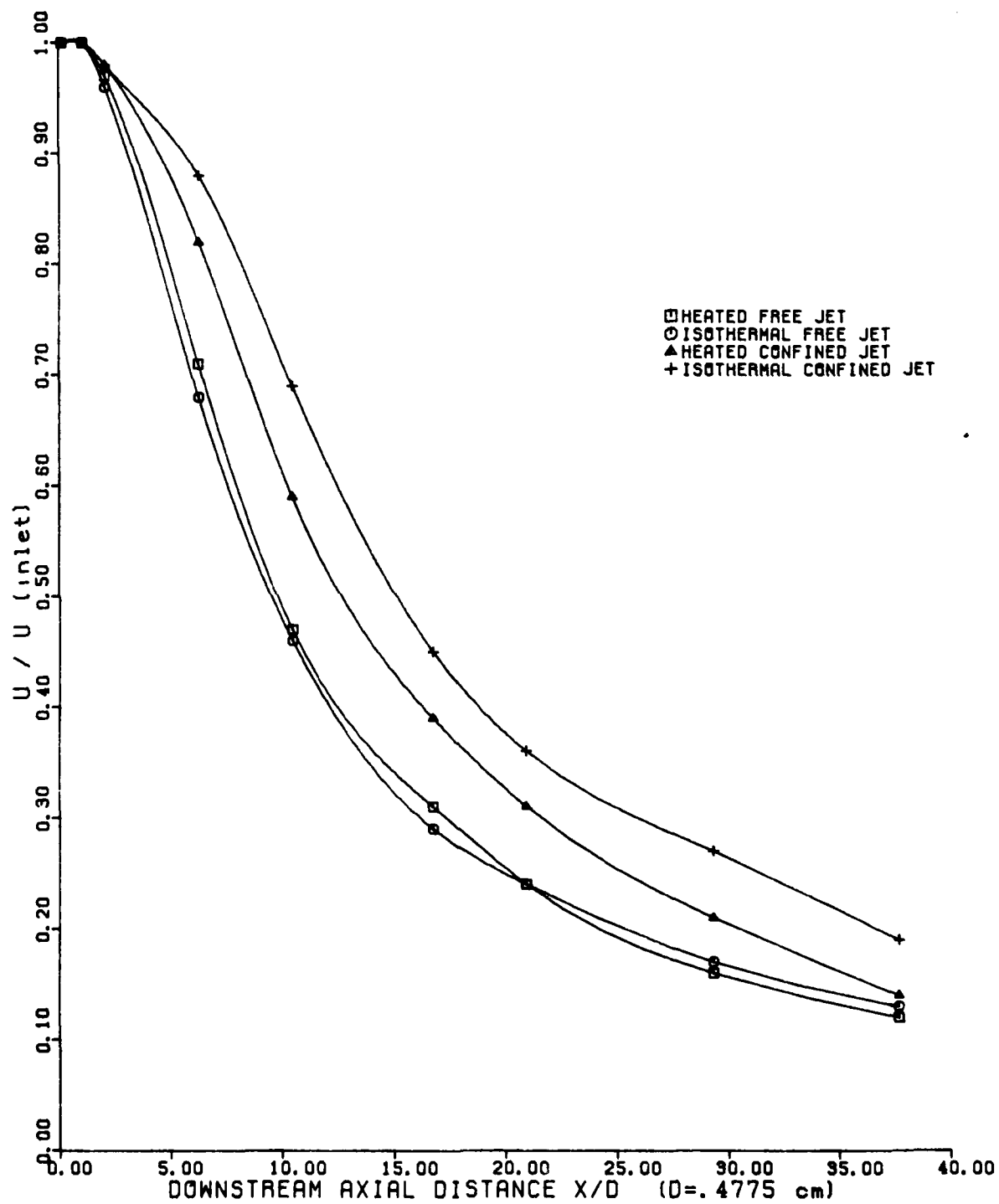


FIGURE 23

Normalized Centerline Velocity Profiles

TABLE 5

CURVE FIT PARAMETERS			
A		a/D	Test No.
4.8	11.2	-4.9	1, Heated Free Jet
4.8	10.5	-4.3	2, Isothermal Free Jet
6.1	11.5	-5.4	3, Heated Confined Jet
6.6	10.6	-5.2	4, Isothermal Confined Jet

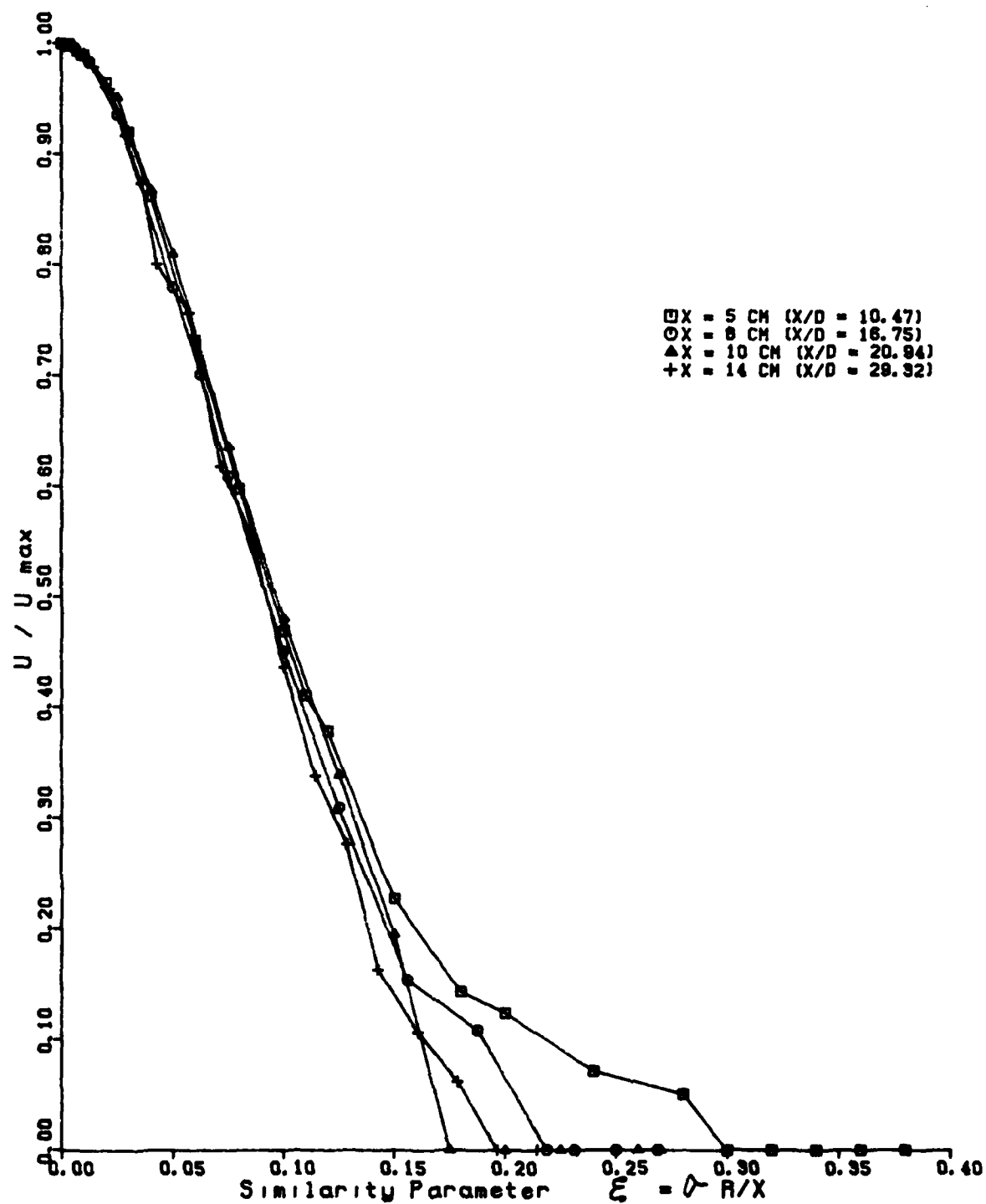


FIGURE 24

Geometric Similarity of Radial Velocity Profiles, Heated Free Jet

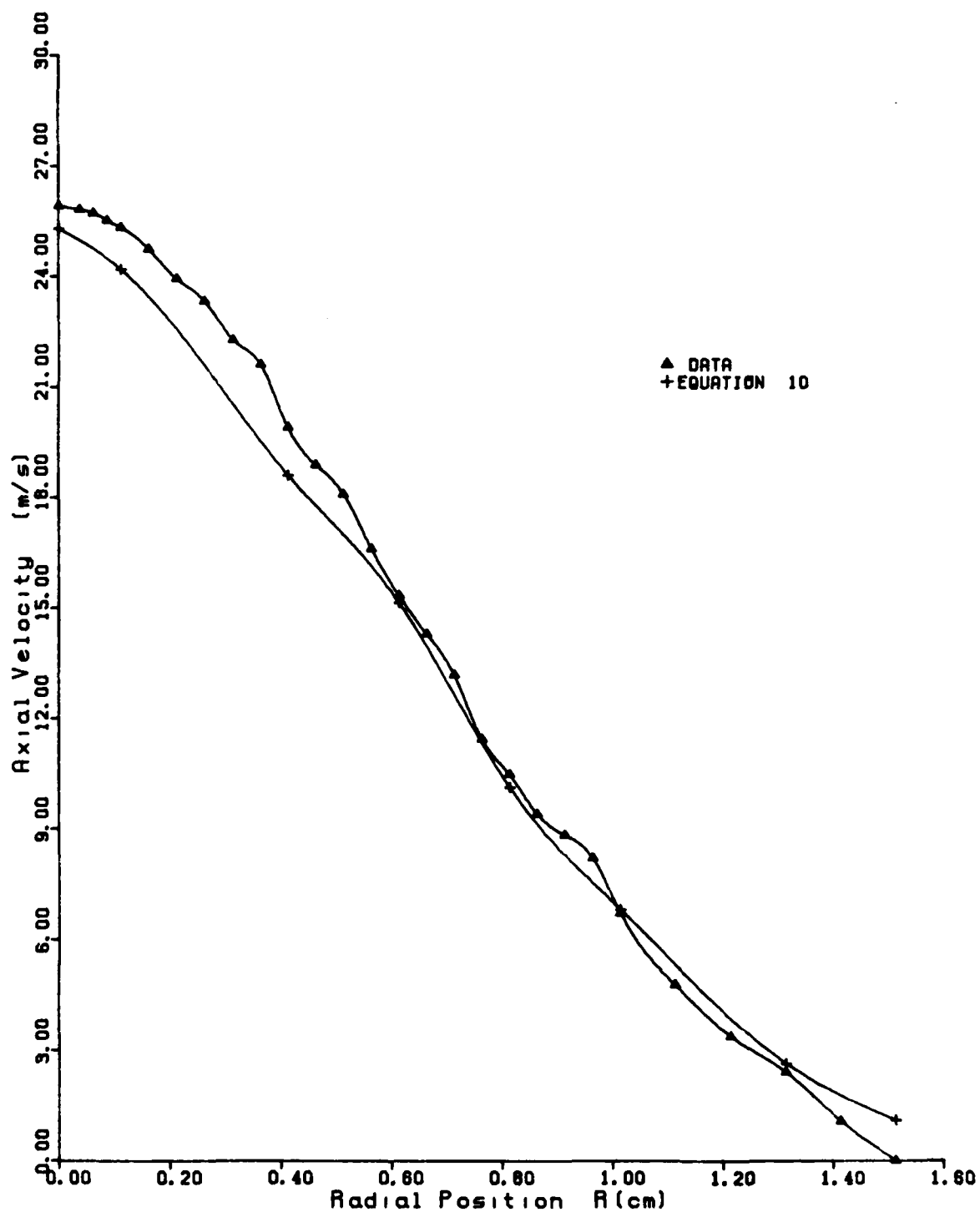


FIGURE 25

Velocity Comparison, Isothermal Free Jet $X/D = 10.5$

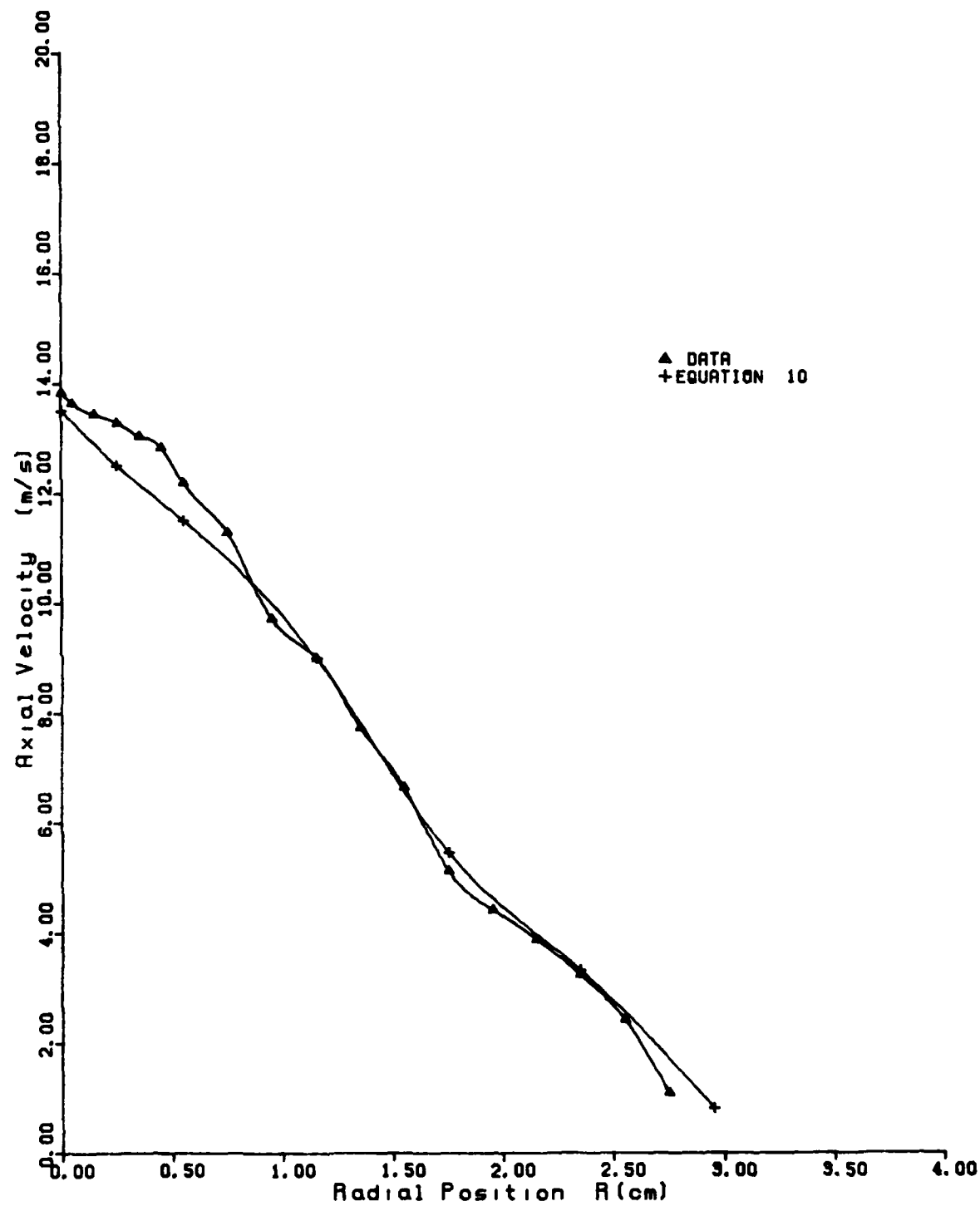


FIGURE 26

Velocity Comparison, Isothermal Free Jet $X/D = 20.9$

1. The velocity increases in the shear layer at the jet exit, due to a larger gradient in density than pressure and the presence of the bluff body.
2. Velocity, temperature, and mass spreading rates are different in the three regions of a jet.
 - a. Velocity > temperature, mass $X/D < 5$
 - b. Velocity = temperature = mass $5 < X/D < 10$
 - c. Temperature, mass > velocity $X/D > 10$
 - d. Temperature = mass, all regions
3. A jet with a higher velocity, whether from heating or increased mass flow, spreads slower and entrains more air than a lower velocity jet at the same axial location.
4. A free jet spreads faster and entrains more air than a confined jet.
5. The confined jets, whether heated or not, spread at about the same rate in the fully developed region of the jet.
6. Isokinetic gas sampling is important for $X/D > 10$ to obtain accurate CO_2 concentrations.

IV. Conclusions And Recommendations

Conclusions

The effects of confinement and jet density on the spreading and entrainment rates of an axisymmetrical CO_2 jet were studied. Four experiments were performed to isolate these effects: heated free jet; isothermal free jet; heated confined jet; and isothermal confined jet. The spreading and entrainment rates were determined from time average measurements of velocity, CO_2 concentration, and temperature made with a modified pitot-static probe.

The confinement noticeably reduced both the spreading and entrainment rate of the jet compared to the free jet. For the isothermal jet studies, the spreading and entrainment rates were lowered by 50% and 30%, respectively. In the heated jet studies, the spreading and entrainment rates were by 30% and 60%, respectively. These reductions were believed due to a mild adverse pressure gradient in the tunnel as well as the presence of the confinement itself.

The density of a jet relative to its surroundings also influences the spreading and entrainment characteristics of the jet. In the isothermal jet studies, the density of the CO_2 jet was 1.5 times that of the surrounding air, while for the heated jet studies the densities of the jet and surrounding air were equal. It was determined that the heated jet spread at a slower rate than the isothermal jet when normalized by nozzle exit conditions. On the other hand, the heated jet entrained more air than the isothermal jet. Both of these phenomena are believed due to the velocity difference between the heated and

isothermal jets (87 m/s and 56 m/s, respectively). Flow visualization studies confirm that the lower velocity isothermal jet penetrates to a greater radial distance and entrains less surrounding air than the higher velocity heated jet.

Recommendations

It is not clear whether the jet exit velocity or density difference is the more important parameter that effects spreading and entrainment. A further point of investigation might be to hold exit velocity constant for these studies and vary temperature.

Also, it is possible that the large overheat (150 K) altered the thermodynamic and transport properties of the jet. An experiment with only 10 to 30 degrees of heating would prove useful in comparison to the isothermal jet.

It would be interesting to see if the velocity increase seen in the shear layer of the jet at the entrance plane is a characteristic of wall jets or of this phenomenon is also present in free jets. In order to determine if this velocity increase is caused by the probe, non-intrusive measurements (laser doppler anemometry) should be performed in conjunction with probe measurements.

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APPENDIX A: DATA FOR HEATED FREE JET

TABLE 6

Data for Heated Free Jet $X/D = 0.105$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.9997	0.6581	0.7996	450.1	87.65	1.181
2	0.045	0.9997	0.6581	0.7996	450.1	87.65	1.181
3	0.095	0.9991	0.6580	0.7980	450.1	87.65	1.181
4	0.120	0.9984	0.6578	0.7970	449.3	87.59	1.182
5	0.145	0.9977	0.6560	0.7900	446.9	87.26	1.188
6	0.170	0.9966	0.6510	0.7810	433.5	85.65	1.224
7	0.180	0.9943	0.6480	0.7760	427.4	84.91	1.239
8	0.190	0.9926	0.6440	0.7720	421.3	84.07	1.256
9	0.195	0.9895	0.6420	0.7700	418.2	83.70	1.264
10	0.200	0.9560	0.6390	0.7670	414.6	83.87	1.253
11	0.205	0.9170	0.6350	0.7640	410.4	83.99	1.241
12	0.210	0.8415	0.6320	0.7610	404.3	84.72	1.214
13	0.215	0.7870	0.6190	0.7470	401.2	84.61	1.192
14	0.220	0.7060	0.5990	0.7210	395.1	84.16	1.166
15	0.225	0.6420	0.5790	0.6910	387.2	83.11	1.156
16	0.230	0.5631	0.5060	0.5340	381.2	78.65	1.128
17	0.235	0.4820	0.3470	0.3990	374.4	65.59	1.112
18	0.240	0.4010	0.2090	0.2350	369.4	51.44	1.089
19	0.245	0.3227	0.1250	0.1350	364.2	40.13	1.071
20	0.250	0.2520	0.0630	0.0650	360.1	28.72	1.053
21	0.255	0.1829	0.0160	0.0160	357.0	14.60	1.036
22	0.260	0.1146	0.0008	0.0008	354.9	3.29	1.016
23	0.265	0.0837	0.0000	0.0000	350.5	0.37	1.018
24	0.275	0.0409	0.0000	0.0000	344.1	0.00	1.022
25	0.280	0.0214	0.0000	0.0000	342.7	0.00	1.019
26	0.285	0.0174	0.0000	0.0000	340.2	0.00	1.025
27	0.290	0.0112	0.0000	0.0000	338.3	0.00	1.029
28	0.295	0.0070	0.0000	0.0000	336.4	0.00	1.033
29	0.300	0.0056	0.0000	0.0000	334.2	0.00	1.039
30	0.305	0.0047	0.0000	0.0000	332.1	0.00	1.045
31	0.310	0.0039	0.0000	0.0000	330.1	0.00	1.051
32	0.315	0.0031	0.0000	0.0000	328.3	0.00	1.057
33	0.320	0.0028	0.0000	0.0000	326.2	0.00	1.064
34	0.345	0.0005	0.0000	0.0000	318.3	0.00	1.089
35	0.370	0.0005	0.0000	0.0000	311.3	0.00	1.114
36	0.395	0.0005	0.0000	0.0000	308.4	0.00	1.124
37	0.445	0.0005	0.0000	0.0000	303.4	0.00	1.143
38	0.545	0.0005	0.0000	0.0000	301.0	0.00	1.152
39	0.645	0.0005	0.0000	0.0000	300.2	0.00	1.155

TABLE 7

Data for Heated Free Jet $X/D = 1.047$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.9997	0.6550	0.7890	450.2	87.47	1.180
2	0.010	0.9997	0.6550	0.7890	450.2	87.48	1.180
3	0.030	0.9997	0.6540	0.7870	450.2	87.41	1.180
4	0.050	0.9994	0.6530	0.7860	449.2	87.26	1.183
5	0.070	0.9971	0.6520	0.7830	448.3	87.16	1.183
6	0.090	0.9945	0.6510	0.7810	445.5	86.88	1.189
7	0.115	0.9920	0.6480	0.7790	441.2	86.31	1.200
8	0.140	0.9800	0.6400	0.7700	432.1	85.15	1.217
9	0.145	0.9726	0.6380	0.7670	430.9	85.07	1.216
10	0.150	0.9540	0.6320	0.7580	428.6	84.85	1.210
11	0.155	0.9366	0.6240	0.7480	426.4	84.47	1.206
12	0.160	0.9199	0.6150	0.7390	423.7	83.95	1.203
13	0.165	0.8897	0.6060	0.7290	420.3	83.61	1.195
14	0.170	0.8738	0.5960	0.7140	417.7	83.01	1.193
15	0.175	0.8577	0.5860	0.7010	413.9	82.25	1.194
16	0.180	0.8328	0.5700	0.6870	409.9	81.22	1.192
17	0.185	0.7977	0.5540	0.6660	406.8	80.45	1.180
18	0.190	0.7682	0.5390	0.6500	403.8	79.60	1.173
19	0.195	0.7400	0.5180	0.6290	401.2	78.30	1.165
20	0.200	0.7153	0.4970	0.6060	398.2	76.83	1.161
21	0.205	0.6903	0.4760	0.5850	395.1	75.32	1.157
22	0.210	0.6658	0.4630	0.5630	392.6	74.48	1.151
23	0.215	0.6396	0.4490	0.5410	390.2	73.56	1.144
24	0.220	0.6068	0.4380	0.5255	387.9	72.97	1.134
25	0.225	0.5804	0.4270	0.4880	384.8	72.24	1.128
26	0.230	0.5469	0.4160	0.4685	381.8	71.54	1.121
27	0.235	0.5149	0.4050	0.4420	378.5	70.80	1.114
28	0.240	0.4796	0.3850	0.4250	375.7	69.27	1.106
29	0.265	0.3066	0.2610	0.3390	356.1	57.38	1.093
30	0.290	0.1592	0.1500	0.2250	344.7	43.99	1.069
31	0.300	0.1306	0.1170	0.1550	341.6	38.92	1.065
32	0.310	0.1036	0.0900	0.0610	338.3	34.22	1.060
33	0.320	0.0604	0.0700	0.0520	333.4	30.17	1.060
34	0.330	0.0450	0.0520	0.0360	327.6	25.85	1.073
35	0.340	0.0310	0.0360	0.0150	320.9	21.34	1.090
36	0.365	0.0138	0.0113	0.0113	310.4	11.79	1.122
37	0.390	0.0053	0.0025	0.0025	303.3	5.49	1.145
38	0.415	0.0015	0.0005	0.0005	301.3	2.45	1.151
39	0.440	0.0005	0.0000	0.0000	300.2	0.00	1.155

TABLE 8

Data for Heated Free Jet X/D = 2.094

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.9972	0.6190	0.7250	449.8	85.13	1.178
2	0.020	0.9966	0.6160	0.7240	448.8	84.99	1.180
3	0.045	0.9926	0.6170	0.7230	446.8	84.82	1.183
4	0.070	0.9862	0.6090	0.7150	442.8	84.02	1.189
5	0.095	0.9796	0.5960	0.7040	439.8	82.98	1.194
6	0.120	0.9599	0.5830	0.6850	432.8	81.84	1.200
7	0.145	0.9258	0.5540	0.6580	424.3	79.67	1.204
8	0.150	0.9146	0.5500	0.6500	422.2	79.41	1.203
9	0.155	0.9027	0.5430	0.6420	420.7	79.00	1.200
10	0.160	0.8660	0.5320	0.6340	418.6	78.69	1.185
11	0.165	0.8501	0.5210	0.6230	416.6	77.99	1.181
12	0.170	0.8345	0.5100	0.6140	413.5	77.16	1.181
13	0.175	0.8216	0.4920	0.6010	411.5	75.82	1.180
14	0.180	0.8042	0.4830	0.5890	409.6	75.27	1.176
15	0.185	0.7923	0.4720	0.5610	408.5	74.56	1.171
16	0.190	0.7649	0.4610	0.5310	406.5	74.02	1.160
17	0.195	0.7133	0.4500	0.5070	404.3	73.84	1.138
18	0.205	0.6629	0.4260	0.4690	401.6	72.45	1.119
19	0.215	0.6165	0.3920	0.4390	397.5	69.84	1.108
20	0.225	0.5882	0.3610	0.3920	391.4	66.95	1.111
21	0.235	0.5323	0.3290	0.3590	387.3	64.33	1.096
22	0.245	0.4474	0.3010	0.3290	384.6	62.40	1.066
23	0.270	0.3500	0.2290	0.2540	375.2	54.81	1.051
24	0.295	0.2940	0.1650	0.1970	364.6	46.35	1.059
25	0.320	0.2181	0.1150	0.1370	356.2	38.80	1.053
26	0.345	0.1509	0.0730	0.0830	350.3	31.05	1.044
27	0.370	0.0648	0.0460	0.0520	340.4	24.68	1.042
28	0.395	0.0406	0.0305	0.0310	333.5	19.98	1.054
29	0.420	0.0228	0.0153	0.0153	316.7	13.63	1.103
30	0.445	0.0106	0.0081	0.0082	312.1	10.01	1.115
31	0.470	0.0008	0.0010	0.0011	308.1	3.50	1.125
32	0.495	0.0005	0.0005	0.0005	304.4	2.46	1.139
33	0.545	0.0005	0.0000	0.0000	302.4	0.00	1.146
34	0.595	0.0005	0.0000	0.0000	301.9	0.00	1.148
35	0.645	0.0005	0.0000	0.0000	300.2	0.00	1.155
36	0.695	0.0005	0.0000	0.0000	300.1	0.00	1.155

TABLE 9

Data for Heated Free Jet $X/D = 6.283$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.6152	0.3150	0.3840	394.1	62.31	1.119
2	0.025	0.6074	0.3130	0.3820	393.5	62.16	1.117
3	0.050	0.6018	0.3090	0.3740	392.0	61.73	1.118
4	0.075	0.5901	0.3010	0.3640	389.9	60.92	1.118
5	0.100	0.5808	0.2860	0.3460	388.2	59.37	1.119
6	0.125	0.5603	0.2720	0.3280	386.3	58.02	1.114
7	0.150	0.5421	0.2530	0.3060	383.1	55.95	1.114
8	0.175	0.5206	0.2370	0.2810	381.6	54.30	1.108
9	0.200	0.4968	0.2140	0.2580	378.2	51.62	1.107
10	0.225	0.4760	0.1970	0.2370	374.3	49.49	1.109
11	0.250	0.4539	0.1740	0.2110	371.1	46.53	1.108
12	0.275	0.4281	0.1540	0.1870	367.7	43.80	1.107
13	0.300	0.4054	0.1360	0.1660	364.8	41.19	1.105
14	0.325	0.3766	0.1230	0.1470	361.4	39.22	1.103
15	0.350	0.3512	0.1080	0.1290	358.2	36.77	1.101
16	0.375	0.3289	0.0970	0.1140	355.1	34.85	1.101
17	0.400	0.3077	0.0842	0.0993	352.0	32.46	1.102
18	0.425	0.2850	0.0731	0.0883	348.7	30.24	1.102
19	0.450	0.2623	0.0611	0.0713	345.4	27.64	1.103
20	0.475	0.2411	0.0503	0.0592	342.1	25.06	1.105
21	0.525	0.1945	0.0443	0.0506	336.4	23.52	1.104
22	0.575	0.1610	0.0381	0.0413	332.6	21.83	1.103
23	0.625	0.1272	0.0301	0.0332	327.2	19.36	1.108
24	0.675	0.0938	0.0243	0.0271	322.6	17.37	1.110
25	0.725	0.0690	0.0197	0.0216	319.2	15.63	1.112
26	0.775	0.0323	0.0154	0.0171	315.5	13.83	1.111
27	0.875	0.0166	0.0095	0.0102	309.4	10.78	1.127
28	0.925	0.0118	0.0079	0.0082	304.1	9.76	1.144
29	0.975	0.0062	0.0073	0.0072	303.4	9.38	1.145
30	1.075	0.0020	0.0035	0.0035	301.8	6.48	1.149
31	1.175	0.0005	0.0006	0.0005	300.2	2.68	1.155
32	1.225	0.0005	0.0000	0.0000	300.2	0.00	1.155

TABLE 10

Data for Heated Free Jet X/D = 10.471

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.3843	0.1410	0.1600	349.4	41.23	1.144
2	0.015	0.3832	0.1400	0.1590	349.2	41.08	1.144
3	0.040	0.3819	0.1390	0.1580	349.0	40.94	1.144
4	0.065	0.3798	0.1365	0.1540	348.7	40.57	1.144
5	0.090	0.3773	0.1340	0.1520	348.2	40.18	1.144
6	0.115	0.3756	0.1320	0.1490	347.2	39.84	1.147
7	0.140	0.3727	0.1300	0.1450	346.1	39.50	1.149
8	0.165	0.3697	0.1260	0.1400	345.3	38.87	1.150
9	0.190	0.3655	0.1200	0.1340	344.3	37.91	1.151
10	0.215	0.3592	0.1160	0.1290	343.6	37.28	1.151
11	0.240	0.3544	0.1100	0.1220	342.5	36.28	1.152
12	0.265	0.3502	0.1060	0.1170	341.3	35.56	1.155
13	0.290	0.3405	0.1000	0.1100	340.3	34.58	1.153
14	0.315	0.3300	0.0950	0.1040	339.4	33.72	1.152
15	0.340	0.3142	0.0890	0.0960	338.2	32.68	1.149
16	0.365	0.3067	0.0840	0.0900	336.6	31.73	1.151
17	0.390	0.2921	0.0790	0.0840	335.4	30.80	1.148
18	0.415	0.2826	0.0730	0.0780	334.2	29.61	1.148
19	0.440	0.2698	0.0690	0.0710	333.1	28.81	1.147
20	0.465	0.2589	0.0650	0.0670	331.6	27.96	1.147
21	0.490	0.2460	0.0610	0.0620	330.4	27.10	1.146
22	0.515	0.2319	0.0570	0.0580	329.7	26.24	1.142
23	0.540	0.2187	0.0530	0.0540	328.6	25.32	1.140
24	0.565	0.2037	0.0480	0.0480	327.5	24.12	1.137
25	0.615	0.1929	0.0410	0.0410	323.5	22.20	1.147
26	0.665	0.1792	0.0350	0.0350	320.5	20.47	1.152
27	0.715	0.1525	0.0290	0.0290	317.7	18.64	1.151
28	0.765	0.1187	0.0230	0.0230	314.9	16.63	1.147
29	0.815	0.1049	0.0170	0.0170	313.2	14.29	1.148
30	0.865	0.0897	0.0130	0.0130	311.9	12.50	1.146
31	0.965	0.0649	0.0060	0.0060	308.8	8.49	1.148
32	1.215	0.0421	0.0020	0.0020	305.1	4.89	1.153
33	1.465	0.0132	0.0006	0.0007	302.4	2.68	1.151
34	1.715	0.0055	0.0001	0.0001	300.8	1.09	1.154
35	1.965	0.0012	0.0000	0.0000	300.4	0.00	1.154
36	2.215	0.0005	0.0000	0.0000	300.1	0.00	1.155
37	2.465	0.0005	0.0000	0.0000	300.1	0.00	1.155

TABLE 11

Data for Heated Free Jet X/D = 16.754

Pt#	R(cm)	C02(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.2325	0.0605	0.0685	330.1	27.04	1.141
2	0.025	0.2300	0.0611	0.0682	330.1	27.18	1.140
3	0.050	0.2291	0.0610	0.0680	330.1	27.16	1.140
4	0.075	0.2267	0.0600	0.0670	329.9	26.95	1.139
5	0.125	0.2250	0.0590	0.0660	329.8	26.72	1.139
6	0.175	0.2223	0.0570	0.0630	329.4	26.27	1.139
7	0.225	0.2194	0.0555	0.0620	329.1	25.92	1.139
8	0.275	0.2147	0.0540	0.0580	328.8	25.58	1.138
9	0.325	0.2110	0.0553	0.0580	328.3	25.88	1.138
10	0.375	0.2069	0.0490	0.0540	327.7	24.36	1.136
11	0.425	0.2033	0.0470	0.0510	327.2	23.86	1.139
12	0.475	0.1984	0.0420	0.0460	326.0	22.53	1.141
13	0.575	0.1868	0.0365	0.0370	324.2	20.99	1.142
14	0.675	0.1753	0.0300	0.0300	322.5	19.02	1.143
15	0.775	0.1652	0.0240	0.0240	320.7	17.00	1.145
16	0.875	0.1486	0.0175	0.0175	318.4	14.51	1.147
17	0.975	0.1270	0.0119	0.0119	316.2	11.97	1.146
18	1.225	0.0981	0.0073	0.0073	312.0	9.36	1.149
19	1.475	0.0681	0.0035	0.0035	307.7	6.47	1.153
20	1.725	0.0390	0.0012	0.0012	304.9	3.79	1.152
21	1.975	0.0115	0.0006	0.0006	302.7	2.68	1.149
22	2.225	0.0039	0.0001	0.0001	301.4	1.09	1.152
23	2.475	0.0029	0.0000	0.0000	300.8	0.00	1.153
24	2.725	0.0009	0.0000	0.0000	300.1	0.00	1.155
25	2.975	0.0005	0.0000	0.0000	300.0	0.00	1.156

TABLE 12

Data for Heated Free Jet $X/D = 20.942$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.1699	0.0370	0.0390	325.7	21.25	1.130
2	0.025	0.1697	0.0370	0.0390	325.7	21.25	1.130
3	0.050	0.1697	0.0370	0.0390	325.7	21.25	1.130
4	0.075	0.1697	0.0368	0.0388	325.7	21.19	1.130
5	0.100	0.1697	0.0365	0.0385	325.7	21.11	1.130
6	0.125	0.1697	0.0362	0.0382	325.7	21.02	1.130
7	0.150	0.1697	0.0359	0.0379	325.6	20.93	1.130
8	0.175	0.1693	0.0356	0.0376	325.6	20.84	1.130
9	0.200	0.1689	0.0353	0.0373	325.5	20.75	1.130
10	0.250	0.1679	0.0348	0.0368	325.4	20.61	1.130
11	0.300	0.1656	0.0343	0.0363	324.8	20.44	1.132
12	0.350	0.1657	0.0319	0.0339	324.7	19.72	1.132
13	0.400	0.1645	0.0305	0.0309	323.9	19.26	1.134
14	0.450	0.1610	0.0287	0.0289	323.3	18.68	1.134
15	0.500	0.1588	0.0280	0.0280	323.1	18.45	1.134
16	0.600	0.1522	0.0245	0.0245	322.2	17.25	1.135
17	0.700	0.1447	0.0219	0.0219	321.3	16.31	1.135
18	0.800	0.1369	0.0199	0.0199	320.6	15.55	1.134
19	0.900	0.1276	0.0185	0.0185	319.4	14.99	1.135
20	1.000	0.1201	0.0150	0.0151	318.6	13.50	1.134
21	1.200	0.1029	0.0101	0.0102	315.5	11.06	1.139
22	1.400	0.0876	0.0066	0.0066	312.3	8.92	1.144
23	1.600	0.0808	0.0050	0.0050	309.6	7.74	1.151
24	1.800	0.0568	0.0031	0.0031	307.5	6.10	1.150
25	2.000	0.0163	0.0010	0.0010	304.4	3.47	1.145
26	2.250	0.0085	0.0001	0.0003	301.6	1.09	1.153
27	2.500	0.0058	0.0000	0.0000	300.1	0.00	1.157
28	2.750	0.0032	0.0000	0.0000	300.1	0.00	1.156
29	3.000	0.0006	0.0000	0.0000	300.1	0.00	1.155

TABLE 13

Data for Heated Free Jet $X/D = 29.319$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.1320	0.0144	0.0171	314.4	13.11	1.155
2	0.025	0.1316	0.0144	0.0169	314.3	13.11	1.155
3	0.050	0.1305	0.0143	0.0167	314.3	13.07	1.155
4	0.100	0.1298	0.0142	0.0165	314.1	13.02	1.155
5	0.150	0.1291	0.0138	0.0160	313.9	12.83	1.155
6	0.200	0.1286	0.0136	0.0155	313.7	12.74	1.156
7	0.250	0.1272	0.0133	0.0149	313.5	12.60	1.156
8	0.350	0.1258	0.0127	0.0143	313.2	12.31	1.156
9	0.450	0.1238	0.0121	0.0138	312.9	12.01	1.157
10	0.550	0.1220	0.0115	0.0130	312.8	11.71	1.156
11	0.750	0.1163	0.0104	0.0119	312.5	11.14	1.155
12	0.950	0.1096	0.0095	0.0104	311.6	10.65	1.156
13	1.200	0.1023	0.0070	0.0079	310.5	9.14	1.157
14	1.450	0.0894	0.0046	0.0053	309.4	7.41	1.156
15	1.700	0.0771	0.0039	0.0040	308.2	6.82	1.155
16	1.950	0.0677	0.0033	0.0033	307.5	6.28	1.154
17	2.450	0.0447	0.0020	0.0020	305.3	4.89	1.153
18	2.950	0.0277	0.0010	0.0010	302.3	3.45	1.157
19	3.450	0.0151	0.0004	0.0004	301.6	2.19	1.155
20	3.950	0.0050	0.0000	0.0000	300.8	0.00	1.154
21	4.450	0.0017	0.0000	0.0000	300.4	0.00	1.155
22	4.950	0.0006	0.0000	0.0000	300.1	0.00	1.155

TABLE 14

Data for Heated Free Jet $X/D = 37.696$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.025	0.1005	0.0090	0.0090	310.9	10.37	1.154
2	0.075	0.0999	0.0090	0.0090	310.8	10.37	1.154
3	0.125	0.0992	0.0086	0.0086	310.7	10.13	1.155
4	0.175	0.0981	0.0081	0.0081	310.4	9.83	1.155
5	0.225	0.0965	0.0078	0.0078	310.1	9.65	1.156
6	0.475	0.0927	0.0074	0.0074	309.9	9.40	1.155
7	0.725	0.0898	0.0068	0.0068	309.7	9.01	1.155
8	0.975	0.0868	0.0059	0.0059	309.1	8.39	1.156
9	1.225	0.0828	0.0053	0.0053	308.9	7.96	1.155
10	1.475	0.0784	0.0048	0.0048	308.3	7.57	1.155
11	1.725	0.0720	0.0042	0.0042	307.3	7.08	1.156
12	1.975	0.0693	0.0030	0.0030	306.9	5.98	1.157
13	2.475	0.0595	0.0016	0.0016	305.8	4.37	1.157
14	2.975	0.0461	0.0009	0.0009	304.7	3.28	1.156
15	3.475	0.0305	0.0007	0.0007	301.9	2.88	1.160
16	3.975	0.0166	0.0004	0.0004	300.9	2.18	1.158
17	4.475	0.0123	0.0001	0.0001	300.6	1.09	1.158
18	4.975	0.0050	0.0000	0.0000	300.2	0.00	1.157
19	5.475	0.0008	0.0000	0.0000	300.1	0.00	1.155

APPENDIX B: DATA FOR ISOTHERMAL FREE JET

TABLE 15

Data for Isothermal Free Jet $X/D = 0.105$

Pt#	R(cm)	CO2(msf)	TP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	1.0000	0.4220	0.5100	295.0	56.92	1.796
2	0.035	1.0000	0.4220	0.5100	295.0	56.92	1.796
3	0.060	0.9998	0.4210	0.5090	295.0	56.86	1.796
4	0.085	0.9996	0.4200	0.5085	295.0	56.79	1.796
5	0.110	0.9994	0.4190	0.5080	295.0	56.73	1.796
6	0.135	0.9991	0.4170	0.5070	295.0	56.59	1.795
7	0.160	0.9986	0.4130	0.5030	295.0	56.33	1.795
8	0.185	0.9927	0.4060	0.5000	295.0	55.93	1.790
9	0.190	0.9797	0.4040	0.4960	295.0	55.98	1.778
10	0.195	0.9620	0.4010	0.4930	295.0	56.02	1.762
11	0.200	0.9431	0.3970	0.4880	295.0	56.01	1.745
12	0.205	0.8960	0.3920	0.4810	295.0	56.32	1.704
13	0.210	0.7735	0.3860	0.4690	295.0	57.56	1.606
14	0.215	0.6755	0.3780	0.4600	295.0	58.25	1.536
15	0.220	0.6085	0.3740	0.4530	295.0	58.80	1.492
16	0.225	0.5391	0.3670	0.4420	295.0	59.12	1.448
17	0.230	0.4360	0.3560	0.4270	295.0	59.48	1.387
18	0.235	0.3410	0.3370	0.4040	295.0	58.98	1.336
19	0.240	0.2561	0.3090	0.3710	295.0	57.40	1.293
20	0.245	0.1854	0.2680	0.3210	295.0	54.18	1.259
21	0.250	0.1537	0.2010	0.2280	295.0	47.23	1.242
22	0.255	0.1238	0.1450	0.1680	295.0	40.34	1.229
23	0.260	0.0720	0.0840	0.0850	295.0	31.01	1.205
24	0.270	0.0354	0.0161	0.0161	295.0	13.66	1.189
25	0.275	0.0231	0.0062	0.0081	295.0	8.50	1.184
26	0.280	0.0149	0.0009	0.0011	295.0	3.24	1.181
27	0.285	0.0095	0.0001	0.0001	295.0	1.08	1.179
28	0.290	0.0047	0.0000	0.0000	295.0	0.00	1.177
29	0.295	0.0024	0.0000	0.0000	295.0	0.00	1.176
30	0.300	0.0012	0.0000	0.0000	295.0	0.00	1.175
31	0.305	0.0005	0.0000	0.0000	295.0	0.00	1.175

TABLE 16

Data for Isothermal Free Jet $X/D = 1.047$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	1.0000	0.4100	0.4930	295.0	56.12	1.795
2	0.050	0.9993	0.4100	0.4930	295.0	56.13	1.795
3	0.075	0.9972	0.4090	0.4910	295.0	56.09	1.793
4	0.100	0.9917	0.4060	0.4860	295.0	55.97	1.787
5	0.105	0.9870	0.4050	0.4810	295.0	55.97	1.783
6	0.110	0.9847	0.4040	0.4790	295.0	55.94	1.780
7	0.115	0.9807	0.4010	0.4770	295.0	55.79	1.777
8	0.120	0.9768	0.4020	0.4750	295.0	55.92	1.773
9	0.125	0.9707	0.4010	0.4730	295.0	55.94	1.767
10	0.130	0.9656	0.3990	0.4710	295.0	55.87	1.763
11	0.135	0.9587	0.3970	0.4680	295.0	55.83	1.756
12	0.140	0.9525	0.3950	0.4640	295.0	55.78	1.750
13	0.145	0.9434	0.3930	0.4600	295.0	55.77	1.742
14	0.150	0.9337	0.3910	0.4570	295.0	55.77	1.734
15	0.155	0.9224	0.3890	0.4540	295.0	55.78	1.724
16	0.160	0.9097	0.3860	0.4510	295.0	55.74	1.713
17	0.165	0.8945	0.3830	0.4450	295.0	55.74	1.700
18	0.170	0.8800	0.3790	0.4370	295.0	55.66	1.687
19	0.175	0.8653	0.3720	0.4290	295.0	55.34	1.675
20	0.180	0.8495	0.3650	0.4180	295.0	55.05	1.661
21	0.185	0.8280	0.3560	0.4080	295.0	54.63	1.645
22	0.195	0.7853	0.3360	0.3800	295.0	53.63	1.611
23	0.205	0.7378	0.3090	0.3470	295.0	52.01	1.575
24	0.215	0.6861	0.2800	0.3110	295.0	50.10	1.538
25	0.225	0.6297	0.2570	0.2720	295.0	48.63	1.499
26	0.235	0.5696	0.2270	0.2330	295.0	46.31	1.460
27	0.240	0.5276	0.1960	0.2110	295.0	43.40	1.435
28	0.250	0.4717	0.1710	0.1760	295.0	41.02	1.401
29	0.275	0.3127	0.1110	0.1110	295.0	34.11	1.315
30	0.300	0.1865	0.0680	0.0680	295.0	27.34	1.255
31	0.325	0.1040	0.0430	0.0430	295.0	22.06	1.218
32	0.350	0.0552	0.0210	0.0210	295.0	15.55	1.197
33	0.375	0.0174	0.0015	0.0015	295.0	4.18	1.182
34	0.400	0.0014	0.0001	0.0000	295.0	1.08	1.175
35	0.425	0.0005	0.0000	0.0000	295.0	0.00	1.175

TABLE 17

Data for Isothermal Free Jet X/D = 2.094

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.9925	0.3890	0.4510	295.0	54.81	1.786
2	0.025	0.9924	0.3890	0.4510	295.0	54.81	1.786
3	0.050	0.9837	0.3870	0.4490	295.0	54.79	1.778
4	0.075	0.9646	0.3830	0.4450	295.0	54.77	1.760
5	0.080	0.9477	0.3820	0.4430	295.0	54.94	1.745
6	0.085	0.9381	0.3805	0.4410	295.0	54.96	1.737
7	0.090	0.9345	0.3791	0.4390	295.0	54.91	1.734
8	0.095	0.9257	0.3770	0.4360	295.0	54.88	1.726
9	0.100	0.9154	0.3750	0.4340	295.0	54.88	1.717
10	0.105	0.9082	0.3710	0.4290	295.0	54.69	1.711
11	0.110	0.9011	0.3680	0.4230	295.0	54.56	1.704
12	0.115	0.8932	0.3640	0.4180	295.0	54.38	1.698
13	0.120	0.8848	0.3625	0.4120	295.0	54.38	1.690
14	0.125	0.8774	0.3590	0.4060	295.0	54.22	1.684
15	0.130	0.8730	0.3550	0.3980	295.0	53.99	1.680
16	0.140	0.8511	0.3460	0.3880	295.0	53.58	1.662
17	0.150	0.8288	0.3320	0.3680	295.0	52.78	1.643
18	0.175	0.7701	0.3010	0.3310	295.0	50.96	1.598
19	0.200	0.7022	0.2560	0.3048	295.0	47.70	1.551
20	0.225	0.6354	0.2180	0.2500	295.0	44.70	1.504
21	0.250	0.5553	0.1740	0.1980	295.0	40.64	1.453
22	0.275	0.4823	0.1320	0.1500	295.0	35.95	1.409
23	0.300	0.3945	0.0960	0.1090	295.0	31.21	1.359
24	0.325	0.3171	0.0710	0.0750	295.0	27.25	1.318
25	0.350	0.2367	0.0460	0.0480	295.0	22.27	1.278
26	0.375	0.1593	0.0280	0.0280	295.0	17.63	1.243
27	0.400	0.1184	0.0150	0.0150	295.0	13.00	1.224
28	0.425	0.0758	0.0061	0.0061	295.0	8.35	1.206
29	0.450	0.0471	0.0021	0.0021	295.0	4.92	1.194
30	0.475	0.0353	0.0005	0.0005	295.0	2.41	1.189
31	0.500	0.0169	0.0001	0.0001	295.0	1.08	1.182
32	0.525	0.0126	0.0000	0.0000	295.0	0.00	1.180
33	0.550	0.0073	0.0000	0.0000	295.0	0.00	1.178
34	0.600	0.0005	0.0000	0.0000	295.0	0.00	1.175
35	0.650	0.0005	0.0000	0.0000	295.0	0.00	1.175
36	0.700	0.0005	0.0000	0.0000	295.0	0.00	1.175

TABLE 18

Data for Isothermal Free Jet $X/D = 6.283$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.6047	0.1606	0.1950	295.0	38.62	1.485
2	0.025	0.6043	0.1605	0.1940	295.0	38.62	1.484
3	0.037	0.6035	0.1600	0.1930	295.0	38.56	1.484
4	0.062	0.5965	0.1590	0.1910	295.0	38.50	1.479
5	0.087	0.5924	0.1540	0.1860	295.0	37.92	1.477
6	0.137	0.5672	0.1440	0.1740	295.0	36.87	1.461
7	0.187	0.5433	0.1280	0.1530	295.0	34.95	1.445
8	0.237	0.5125	0.1080	0.1300	295.0	32.31	1.427
9	0.288	0.4727	0.0920	0.1070	295.0	30.07	1.403
10	0.337	0.4237	0.0750	0.0880	295.0	27.42	1.375
11	0.388	0.3774	0.0610	0.0710	295.0	24.96	1.350
12	0.438	0.3360	0.0460	0.0520	295.0	21.86	1.328
13	0.487	0.3043	0.0365	0.0370	295.0	19.59	1.311
14	0.537	0.2581	0.0281	0.0280	295.0	17.34	1.289
15	0.588	0.2125	0.0203	0.0200	295.0	14.86	1.267
16	0.638	0.1710	0.0132	0.0130	295.0	12.08	1.246
17	0.688	0.1389	0.0092	0.0090	295.0	10.14	1.233
18	0.737	0.1108	0.0054	0.0050	295.0	7.81	1.221
19	0.787	0.0794	0.0030	0.0030	295.0	5.85	1.208
20	0.838	0.0540	0.0010	0.0010	295.0	3.39	1.197
21	0.887	0.0430	0.0007	0.0007	295.0	2.85	1.192
22	0.937	0.0325	0.0003	0.0003	295.0	1.87	1.188
23	0.987	0.0280	0.0000	0.0000	295.0	0.00	1.186
24	1.087	0.0047	0.0000	0.0000	295.0	0.00	1.177
25	1.187	0.0017	0.0000	0.0000	295.0	0.00	1.176
26	1.287	0.0006	0.0000	0.0000	295.0	0.00	1.175

TABLE 19

Data for Isothermal Free Jet X/D = 10.471

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.3854	0.0650	0.0802	295.0	25.92	1.354
2	0.037	0.3855	0.0655	0.0800	295.0	25.82	1.355
3	0.062	0.3854	0.0650	0.0790	295.0	25.72	1.354
4	0.087	0.3846	0.0640	0.0780	295.0	25.53	1.354
5	0.112	0.3825	0.0630	0.0760	295.0	25.34	1.353
6	0.163	0.3769	0.0600	0.0730	295.0	24.76	1.350
7	0.212	0.3707	0.0560	0.0680	295.0	23.95	1.347
8	0.262	0.3625	0.0530	0.0630	295.0	23.34	1.342
9	0.313	0.3446	0.0480	0.0570	295.0	22.29	1.333
10	0.362	0.3351	0.0450	0.0540	295.0	21.61	1.328
11	0.412	0.3235	0.0380	0.0450	295.0	19.91	1.322
12	0.462	0.3079	0.0340	0.0390	295.0	18.89	1.314
13	0.512	0.2929	0.0310	0.0350	295.0	18.09	1.306
14	0.562	0.2773	0.0260	0.0280	295.0	16.62	1.298
15	0.612	0.2547	0.0220	0.0240	295.0	15.35	1.287
16	0.662	0.2412	0.0190	0.0190	295.0	14.30	1.280
17	0.712	0.2160	0.0160	0.0160	295.0	13.19	1.269
18	0.762	0.2044	0.0120	0.0120	295.0	11.45	1.263
19	0.813	0.1832	0.0100	0.0100	295.0	10.49	1.253
20	0.862	0.1672	0.0080	0.0080	295.0	9.41	1.246
21	0.912	0.1439	0.0070	0.0070	295.0	8.84	1.236
22	0.952	0.1269	0.0060	0.0060	295.0	8.21	1.228
23	1.012	0.1156	0.0040	0.0040	295.0	6.72	1.223
24	1.112	0.0877	0.0020	0.0020	295.0	4.77	1.211
25	1.213	0.0694	0.0010	0.0010	295.0	3.39	1.203
26	1.312	0.0424	0.0005	0.0005	295.0	2.40	1.192
27	1.412	0.0264	0.0001	0.0001	295.0	1.06	1.186
28	1.512	0.0172	0.0000	0.0000	295.0	0.00	1.182
29	1.613	0.0100	0.0000	0.0000	295.0	0.00	1.179
30	1.812	0.0030	0.0000	0.0000	295.0	0.00	1.176
31	2.012	0.0006	0.0000	0.0000	295.0	0.00	1.175

TABLE 20

Data for Isothermal Free Jet X/D = 16.754

Pt#	R(cm)	C02(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.2547	0.0240	0.0300	295.0	16.03	1.287
2	0.040	0.2546	0.0240	0.0300	295.0	16.03	1.287
3	0.090	0.2509	0.0236	0.0290	295.0	15.91	1.286
4	0.190	0.2473	0.0231	0.0280	295.0	15.75	1.284
5	0.290	0.2400	0.0226	0.0270	295.0	15.60	1.280
6	0.390	0.2322	0.0220	0.0260	295.0	15.42	1.277
7	0.490	0.2229	0.0202	0.0245	295.0	14.80	1.272
8	0.590	0.2109	0.0183	0.0221	295.0	14.12	1.267
9	0.690	0.1968	0.0161	0.0203	295.0	13.27	1.260
10	0.790	0.1846	0.0143	0.0171	295.0	12.54	1.254
11	0.890	0.1692	0.0113	0.0142	295.0	11.18	1.247
12	0.990	0.1544	0.0096	0.0107	295.0	10.33	1.240
13	1.190	0.1263	0.0063	0.0081	295.0	8.41	1.228
14	1.390	0.0988	0.0041	0.0047	295.0	6.82	1.216
15	1.590	0.0742	0.0030	0.0030	295.0	5.86	1.205
16	1.790	0.0496	0.0018	0.0018	295.0	4.56	1.195
17	1.990	0.0329	0.0002	0.0002	295.0	1.40	1.188
18	2.190	0.0177	0.0005	0.0005	295.0	2.42	1.182
19	2.390	0.0105	0.0000	0.0000	295.0	0.34	1.179
20	2.590	0.0034	0.0000	0.0000	295.0	0.00	1.176
21	2.790	0.0016	0.0000	0.0000	295.0	0.00	1.176
22	2.990	0.0007	0.0000	0.0000	295.0	0.00	1.175

TABLE 21

Data for Isothermal Free Jet $X/D = 20.942$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.1991	0.0175	0.0195	295.0	13.83	1.261
2	0.050	0.1986	0.0170	0.0190	295.0	13.64	1.261
3	0.150	0.1978	0.0165	0.0180	295.0	13.44	1.260
4	0.250	0.1957	0.0161	0.0170	295.0	13.28	1.259
5	0.350	0.1918	0.0155	0.0160	295.0	13.04	1.257
6	0.450	0.1878	0.0150	0.0155	295.0	12.84	1.256
7	0.550	0.1830	0.0135	0.0141	295.0	12.19	1.253
8	0.750	0.1669	0.0115	0.0120	295.0	11.28	1.246
9	0.950	0.1528	0.0085	0.0089	295.0	9.72	1.240
10	1.150	0.1199	0.0072	0.0076	295.0	9.00	1.225
11	1.350	0.1150	0.0053	0.0055	295.0	7.73	1.223
12	1.550	0.1070	0.0039	0.0040	295.0	6.64	1.219
13	1.750	0.0843	0.0023	0.0024	295.0	5.12	1.210
14	1.950	0.0694	0.0017	0.0017	295.0	4.41	1.203
15	2.150	0.0524	0.0013	0.0013	295.0	3.87	1.196
16	2.350	0.0354	0.0009	0.0009	295.0	3.23	1.189
17	2.550	0.0261	0.0005	0.0005	295.0	2.41	1.185
18	2.750	0.0147	0.0001	0.0001	295.0	1.08	1.181
19	2.950	0.0080	0.0000	0.0000	295.0	0.00	1.178
20	3.450	0.0014	0.0000	0.0000	295.0	0.00	1.175
21	3.700	0.0006	0.0000	0.0000	295.0	0.00	1.175

TABLE 22

Data for Isothermal Free Jet X/D = 29.319

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.1492	0.0088	0.0090	295.0	9.90	1.238
2	0.050	0.1492	0.0088	0.0090	295.0	9.90	1.238
3	0.100	0.1492	0.0087	0.0089	295.0	9.87	1.238
4	0.200	0.1486	0.0087	0.0088	295.0	9.82	1.238
5	0.300	0.1472	0.0086	0.0086	295.0	9.79	1.237
6	0.400	0.1435	0.0084	0.0084	295.0	9.68	1.235
7	0.500	0.1410	0.0080	0.0080	295.0	9.45	1.234
8	0.600	0.1395	0.0075	0.0075	295.0	9.16	1.234
9	0.700	0.1380	0.0071	0.0071	295.0	8.91	1.233
10	0.800	0.1337	0.0066	0.0066	295.0	8.60	1.231
11	0.900	0.1313	0.0061	0.0061	295.0	8.27	1.230
12	1.000	0.1266	0.0057	0.0057	295.0	8.00	1.228
13	1.100	0.1234	0.0054	0.0054	295.0	7.79	1.227
14	1.300	0.1146	0.0045	0.0045	295.0	7.12	1.223
15	1.500	0.1047	0.0035	0.0035	295.0	6.29	1.219
16	1.700	0.0984	0.0027	0.0027	295.0	5.53	1.216
17	1.900	0.0914	0.0023	0.0023	295.0	5.11	1.213
18	2.100	0.0811	0.0018	0.0018	295.0	4.53	1.208
19	2.600	0.0569	0.0011	0.0011	295.0	3.56	1.198
20	3.100	0.0213	0.0006	0.0006	295.0	2.64	1.183
21	3.600	0.0174	0.0001	0.0001	295.0	1.08	1.182
22	4.100	0.0004	0.0000	0.0000	295.0	0.00	1.175
23	4.200	0.0006	0.0000	0.0000	295.0	0.00	1.175

TABLE 23

Data for Isothermal Free Jet X/D = 37.696

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.1055	0.0056	0.0056	295.0	7.96	1.219
2	0.100	0.1045	0.0056	0.0056	295.0	7.95	1.218
3	0.200	0.1033	0.0055	0.0055	295.0	7.91	1.218
4	0.300	0.1026	0.0055	0.0055	295.0	7.89	1.218
5	0.400	0.1019	0.0053	0.0053	295.0	7.75	1.217
6	0.500	0.1012	0.0051	0.0051	295.0	7.64	1.217
7	0.600	0.1005	0.0050	0.0050	295.0	7.57	1.217
8	0.700	0.0999	0.0049	0.0049	295.0	7.44	1.216
9	0.800	0.0994	0.0047	0.0048	295.0	7.30	1.216
10	1.000	0.0951	0.0045	0.0045	295.0	7.15	1.214
11	1.200	0.0921	0.0041	0.0041	295.0	6.83	1.213
12	1.400	0.0857	0.0037	0.0037	295.0	6.49	1.210
13	1.600	0.0804	0.0034	0.0034	295.0	6.23	1.206
14	1.800	0.0749	0.0030	0.0030	295.0	5.86	1.206
15	2.000	0.0716	0.0025	0.0025	295.0	5.35	1.204
16	2.300	0.0688	0.0021	0.0021	295.0	4.91	1.203
17	2.800	0.0587	0.0018	0.0018	295.0	4.55	1.199
18	3.300	0.0446	0.0010	0.0010	295.0	3.40	1.193
19	3.800	0.0253	0.0000	0.0000	295.0	0.00	1.185
20	4.300	0.0177	0.0000	0.0000	295.0	0.00	1.182
21	4.800	0.0121	0.0000	0.0000	295.0	0.00	1.180
22	5.050	0.0006	0.0000	0.0000	295.0	0.00	1.175

APPENDIX C: DATA FOR HEATED CONFINED JET

TABLE 24

Data for Heated Confined Jet $X/D = 0.105$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.9951	0.5940	0.7290	450.1	83.39	1.178
2	0.050	0.9951	0.5950	0.7290	450.1	83.46	1.178
3	0.100	0.9917	0.5830	0.7130	450.0	82.69	1.176
4	0.150	0.9891	0.5690	0.6950	426.0	79.55	1.240
5	0.175	0.9811	0.5650	0.6930	404.0	77.35	1.302
6	0.200	0.9778	0.5640	0.6910	373.0	74.32	1.408
7	0.205	0.9736	0.5550	0.6830	370.0	73.50	1.417
8	0.210	0.9602	0.5460	0.6710	369.0	72.96	1.414
9	0.215	0.8731	0.5390	0.6620	364.0	73.69	1.369
10	0.220	0.7655	0.5300	0.6500	360.0	74.55	1.315
11	0.225	0.6356	0.5210	0.6370	357.0	75.80	1.250
12	0.230	0.5206	0.4900	0.5980	352.0	74.03	1.200
13	0.235	0.3919	0.4600	0.5610	348.0	74.01	1.150
14	0.240	0.3339	0.4050	0.4930	342.0	69.66	1.151
15	0.245	0.2623	0.3240	0.3930	339.0	62.92	1.128
16	0.250	0.1433	0.2280	0.2760	335.0	53.67	1.092
17	0.255	0.0413	0.1340	0.1590	334.0	41.86	1.054
18	0.260	0.0214	0.0620	0.0690	332.0	28.51	1.052
19	0.265	0.0144	0.0190	0.0170	331.0	15.78	1.052
20	0.275	0.0107	0.0000	-0.0020	328.0	0.00	1.060
21	0.285	0.0071	0.0000	-0.0010	323.0	0.00	1.076
22	0.300	0.0012	0.0000	0.0000	320.0	0.00	1.084
23	0.320	0.0005	0.0000	0.0000	318.0	0.00	1.090
24	0.350	0.0005	0.0000	0.0000	311.0	0.00	1.115
25	0.375	0.0005	0.0000	0.0000	308.0	0.00	1.125
26	0.400	0.0005	0.0000	0.0000	307.0	0.00	1.129
27	0.425	0.0005	0.0000	0.0000	307.0	0.00	1.129
28	0.450	0.0005	0.0000	0.0000	305.0	0.00	1.137
29	0.475	0.0005	0.0000	0.0000	305.0	0.00	1.137

TABLE 25

Data for Heated Confined Jet X/D = 1.047

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	1.0000	0.5840	0.6810	450.0	82.68	1.178
2	0.035	1.0000	0.5840	0.6810	450.0	82.68	1.178
3	0.050	1.0000	0.5840	0.6810	450.0	82.68	1.178
4	0.065	1.0000	0.5840	0.6810	450.0	82.68	1.178
5	0.070	1.0000	0.5840	0.6810	450.0	82.68	1.178
6	0.075	0.9993	0.5838	0.6810	449.2	82.60	1.180
7	0.080	0.9991	0.5834	0.6800	448.4	82.51	1.182
8	0.083	0.9978	0.5831	0.6810	448.5	82.52	1.181
9	0.095	0.9954	0.5828	0.6805	444.1	82.15	1.191
10	0.100	0.9939	0.5825	0.6810	440.0	81.77	1.201
11	0.105	0.9894	0.5820	0.6790	435.7	81.44	1.210
12	0.115	0.9906	0.5815	0.6780	429.9	80.83	1.227
13	0.125	0.9782	0.5810	0.6770	424.2	80.52	1.236
14	0.135	0.9513	0.5800	0.6770	419.8	80.58	1.232
15	0.145	0.9333	0.5760	0.6760	414.1	80.26	1.237
16	0.155	0.8915	0.5770	0.6750	409.7	80.59	1.225
17	0.170	0.8149	0.5755	0.6700	400.1	81.03	1.209
18	0.180	0.7631	0.5745	0.6685	394.1	81.33	1.198
19	0.195	0.6490	0.5720	0.6670	385.0	82.30	1.165
20	0.220	0.4240	0.5370	0.6230	371.6	82.15	1.097
21	0.230	0.3772	0.5050	0.5840	366.4	79.86	1.092
22	0.250	0.2753	0.4390	0.4990	357.0	75.00	1.076
23	0.270	0.1677	0.2880	0.3180	342.0	60.72	1.077
24	0.295	0.0658	0.1470	0.1560	329.2	43.37	1.078
25	0.320	0.0258	0.0680	0.0710	324.0	29.47	1.079
26	0.345	0.0216	0.0550	0.0560	316.3	26.21	1.104
27	0.370	0.0148	0.0410	0.0410	309.2	22.40	1.127
28	0.395	0.0077	0.0290	0.0290	305.3	18.74	1.138
29	0.420	0.0014	0.0170	0.0170	302.3	14.30	1.147
30	0.445	0.0005	0.0060	0.0060	301.8	8.49	1.148
31	0.495	0.0000	0.0000	0.0000	301.2	0.00	1.151

TABLE 26

Data for Heated Confined Jet X/D = 2.094

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	1.0000	0.5470	0.6550	444.5	79.49	1.194
2	0.050	0.9984	0.5470	0.6550	439.7	79.10	1.206
3	0.075	0.9915	0.5430	0.6490	435.2	78.55	1.214
4	0.100	0.9734	0.5420	0.6470	427.9	78.18	1.223
5	0.105	0.9718	0.5410	0.6460	426.1	77.98	1.227
6	0.110	0.9576	0.5400	0.6450	424.2	78.01	1.224
7	0.115	0.9477	0.5410	0.6440	423.0	78.18	1.221
8	0.125	0.9340	0.5380	0.6440	420.1	77.95	1.221
9	0.135	0.9139	0.5350	0.6410	414.3	77.59	1.225
10	0.145	0.8918	0.5210	0.6310	413.7	76.91	1.215
11	0.165	0.8384	0.4930	0.5890	406.0	75.12	1.205
12	0.180	0.7944	0.4640	0.5520	401.0	73.21	1.194
13	0.200	0.7237	0.4120	0.4880	393.5	69.49	1.177
14	0.225	0.6336	0.3300	0.3870	384.5	62.76	1.155
15	0.250	0.5457	0.2430	0.2860	375.6	54.27	1.138
16	0.275	0.4428	0.1670	0.1930	365.9	45.38	1.118
17	0.300	0.3176	0.1070	0.1230	356.2	36.75	1.093
18	0.325	0.2259	0.0660	0.0720	350.5	29.14	1.072
19	0.350	0.1501	0.0360	0.0360	339.2	21.47	1.077
20	0.375	0.0903	0.0180	0.0180	330.7	15.15	1.081
21	0.400	0.0530	0.0070	0.0070	323.5	9.41	1.091
22	0.475	0.0104	0.0010	0.0020	314.6	3.53	1.106
23	0.500	0.0088	0.0005	0.0005	310.2	2.48	1.121
24	0.550	0.0047	0.0000	0.0000	306.4	0.00	1.133
25	0.600	0.0014	0.0000	0.0000	303.1	0.00	1.144
26	0.650	0.0005	0.0000	0.0000	300.2	0.00	1.155

TABLE 27

Data for Heated Confined Jet X/D = 4.188

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.9362	0.5080	0.6200	435.2	77.04	1.180
2	0.060	0.9294	0.5050	0.6170	428.1	76.31	1.196
3	0.110	0.8367	0.4440	0.5420	419.7	72.51	1.164
4	0.135	0.8006	0.4060	0.4950	412.6	69.36	1.164
5	0.160	0.7509	0.3660	0.4450	404.1	65.96	1.160
6	0.185	0.7035	0.3280	0.3980	397.4	62.61	1.154
7	0.210	0.6589	0.2910	0.3390	391.3	58.10	1.148
8	0.235	0.6104	0.2350	0.2830	384.1	53.22	1.144
9	0.260	0.5543	0.1930	0.2320	379.4	48.53	1.130
10	0.285	0.5027	0.1550	0.1850	373.9	43.65	1.122
11	0.310	0.4399	0.1190	0.1430	366.2	38.35	1.116
12	0.335	0.3684	0.0910	0.1100	360.1	33.73	1.103
13	0.360	0.3140	0.0690	0.0830	355.1	29.48	1.094
14	0.385	0.2725	0.0510	0.0600	350.8	25.40	1.090
15	0.410	0.2213	0.0370	0.0430	345.2	21.67	1.087
16	0.435	0.1751	0.0250	0.0300	340.8	17.85	1.082
17	0.460	0.1324	0.0160	0.0190	334.8	14.26	1.084
18	0.485	0.1039	0.0100	0.0110	330.0	11.25	1.089
19	0.535	0.0574	0.0040	0.0040	322.0	7.09	1.098
20	0.585	0.0326	0.0020	0.0020	316.4	4.99	1.108
21	0.635	0.0159	0.0010	0.0010	308.2	3.49	1.131
22	0.685	0.0080	0.0001	0.0001	303.6	1.10	1.145
23	0.735	0.0012	0.0000	0.0000	302.8	0.00	1.145
24	0.760	0.0005	0.0000	0.0000	301.6	0.00	1.150

TABLE 28

Data for Heated Confined Jet X/D = 6.283

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.7855	0.3960	0.4910	408.4	68.38	1.168
2	0.020	0.7855	0.3940	0.4860	407.5	68.14	1.170
3	0.060	0.7624	0.3820	0.4720	405.3	67.28	1.164
4	0.085	0.7453	0.3670	0.4540	402.8	66.01	1.162
5	0.110	0.7177	0.3450	0.4250	499.8	71.75	0.924
6	0.135	0.6951	0.3175	0.3920	395.9	61.59	1.154
7	0.160	0.6698	0.2905	0.3570	391.3	58.92	1.154
8	0.210	0.5938	0.2305	0.2830	383.9	52.88	1.137
9	0.260	0.5228	0.1755	0.2160	375.2	46.32	1.128
10	0.310	0.4538	0.1295	0.1580	369.8	40.08	1.112
11	0.360	0.3701	0.0920	0.1120	359.5	33.88	1.105
12	0.410	0.3097	0.0615	0.0740	353.6	27.80	1.097
13	0.460	0.2457	0.0395	0.0480	345.9	22.31	1.094
14	0.485	0.2176	0.0315	0.0390	342.7	19.93	1.093
15	0.510	0.1862	0.0235	0.0290	338.2	17.20	1.095
16	0.560	0.1360	0.0135	0.0160	331.9	13.04	1.095
17	0.610	0.0933	0.0075	0.0080	325.0	9.69	1.102
18	0.660	0.0622	0.0035	0.0045	320.7	6.61	1.104
19	0.760	0.0249	0.0008	0.0009	314.7	3.15	1.111
20	1.010	0.0005	0.0003	0.0003	308.0	1.92	1.125
21	1.260	0.0005	0.0000	0.0000	301.1	0.00	1.151

TABLE 29

Data for Heated Confined Jet X/D = 8.377

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.6374	0.2860	0.3530	384.7	58.37	1.157
2	0.010	0.6370	0.2852	0.3520	384.1	58.25	1.159
3	0.050	0.6315	0.2762	0.3400	382.7	57.30	1.160
4	0.100	0.6257	0.2552	0.3150	382.0	55.10	1.159
5	0.150	0.5760	0.2232	0.2750	378.9	51.89	1.143
6	0.200	0.5264	0.1882	0.2320	376.2	47.99	1.127
7	0.300	0.4274	0.1212	0.1490	365.2	38.74	1.113
8	0.400	0.3355	0.0712	0.0870	353.5	29.76	1.109
9	0.500	0.2431	0.0362	0.0450	341.6	21.23	1.107
10	0.600	0.1665	0.0202	0.0210	330.4	15.82	1.112
11	0.700	0.1012	0.0097	0.0097	323.8	10.98	1.109
12	0.800	0.0553	0.0057	0.0057	314.2	8.36	1.125
13	0.900	0.0278	0.0033	0.0033	309.9	6.35	1.129
14	1.000	0.0138	0.0015	0.0015	308.2	4.28	1.130
15	1.200	0.0030	0.0009	0.0009	306.2	3.31	1.133
16	1.400	0.0007	0.0002	0.0002	305.9	1.56	1.133
17	1.500	0.0005	0.0000	0.0000	304.7	0.00	1.138
18	1.600	0.0005	0.0000	0.0000	302.2	0.00	1.147
19	1.700	0.0005	0.0000	0.0000	300.4	0.00	1.154

TABLE 30

Data for Heated Confined Jet X/D = 10.471

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.5266	0.1970	0.2450	372.7	48.86	1.138
2	0.010	0.5266	0.1970	0.2450	372.2	48.83	1.139
3	0.050	0.5214	0.1930	0.2400	371.9	48.36	1.138
4	0.100	0.5058	0.1830	0.2270	370.1	47.14	1.136
5	0.150	0.4924	0.1670	0.2070	366.5	44.94	1.140
6	0.200	0.4652	0.1470	0.1820	361.1	42.09	1.144
7	0.300	0.3886	0.1050	0.1310	353.7	35.77	1.132
8	0.400	0.3314	0.0700	0.0870	345.6	29.19	1.133
9	0.500	0.2710	0.0430	0.0540	338.6	22.92	1.129
10	0.550	0.2389	0.0330	0.0420	334.3	20.07	1.130
11	0.600	0.2083	0.0280	0.0320	330.8	18.50	1.128
12	0.750	0.1294	0.0100	0.0110	324.6	11.11	1.117
13	0.900	0.0681	0.0040	0.0040	315.6	7.00	1.124
14	1.000	0.0403	0.0030	0.0030	310.8	6.05	1.131
15	1.200	0.0122	0.0010	0.0010	305.3	3.48	1.140
16	1.400	0.0027	0.0005	0.0005	303.8	2.46	1.142
17	1.500	0.0014	0.0000	0.0000	302.3	0.00	1.147
18	1.600	0.0005	0.0000	0.0000	301.2	0.00	1.151
19	1.700	0.0005	0.0000	0.0000	300.6	0.00	1.153
20	1.800	0.0005	0.0000	0.0000	300.2	0.00	1.155
21	1.900	0.0005	0.0000	0.0000	300.1	0.00	1.155

TABLE 31

Data for Heated Confined Jet X/D = 12.565

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.4450	0.1440	0.1780	366.8	42.16	1.117
2	0.010	0.4450	0.1440	0.1780	366.2	42.13	1.119
3	0.050	0.4308	0.1420	0.1760	364.8	41.87	1.117
4	0.100	0.4240	0.1360	0.1700	363.1	40.94	1.119
5	0.200	0.4096	0.1160	0.1440	359.1	37.71	1.125
6	0.300	0.3654	0.0900	0.1100	354.8	33.32	1.118
7	0.400	0.3258	0.0660	0.0879	358.5	28.90	1.090
8	0.500	0.2793	0.0480	0.0530	343.6	24.36	1.115
9	0.525	0.2594	0.0410	0.0480	340.3	22.49	1.118
10	0.600	0.2281	0.0300	0.0350	338.6	19.30	1.110
11	0.750	0.1643	0.0160	0.0180	329.1	14.06	1.116
12	0.900	0.1070	0.0080	0.0110	320.9	9.92	1.121
13	1.050	0.0601	0.0030	0.0040	314.3	6.06	1.126
14	1.200	0.0308	0.0020	0.0030	309.0	4.93	1.134
15	1.350	0.0127	0.0010	0.0020	306.0	3.46	1.138
16	1.550	0.0033	0.0005	0.0010	305.1	2.46	1.137
17	1.650	0.0014	0.0001	0.0001	304.4	1.10	1.139
18	1.750	0.0009	0.0000	0.0000	303.9	0.00	1.141
19	1.850	0.0006	0.0000	0.0000	302.0	0.00	1.146
20	2.000	0.0005	0.0000	0.0000	300.6	0.00	1.153

TABLE 32

Data for Heated Confined Jet X/D = 16.754

Pt#	R(cm)	C02(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.3295	0.0830	0.1060	356.5	32.29	1.097
2	0.010	0.3293	0.0830	0.1060	354.9	32.22	1.102
3	0.050	0.3374	0.0830	0.1060	354.4	32.15	1.107
4	0.100	0.3360	0.0810	0.1030	354.2	31.76	1.107
5	0.200	0.3163	0.0730	0.0940	353.4	30.23	1.101
6	0.400	0.2670	0.0510	0.0670	346.8	25.16	1.109
7	0.500	0.2600	0.0410	0.0540	345.4	22.65	1.102
8	0.600	0.2344	0.0310	0.0430	341.7	19.68	1.104
9	0.800	0.1830	0.0170	0.0240	334.5	14.55	1.106
10	1.000	0.1306	0.0080	0.0140	326.7	9.96	1.111
11	1.250	0.0729	0.0020	0.0080	318.0	4.97	1.118
12	1.500	0.0302	0.0010	0.0050	311.7	3.50	1.124
13	1.750	0.0088	0.0000	0.0050	306.4	0.00	1.135
14	1.850	0.0044	0.0000	0.0050	303.9	0.00	1.142
15	2.000	0.0009	0.0000	0.0040	301.8	0.00	1.149
16	2.150	0.0005	0.0000	0.0030	300.5	0.00	1.154

TABLE 33

Data for Heated Confined Jet X/D = 20.942

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.2643	0.0520	0.0690	343.8	25.42	1.110
2	0.050	0.2631	0.0520	0.0690	343.6	25.42	1.110
3	0.100	0.2611	0.0510	0.0680	344.1	25.20	1.107
4	0.250	0.2528	0.0470	0.0630	342.9	24.19	1.108
5	0.400	0.2417	0.0390	0.0540	342.0	22.05	1.106
6	0.500	0.2255	0.0340	0.0470	339.6	20.58	1.107
7	0.750	0.1868	0.0210	0.0320	334.2	16.16	1.109
8	1.000	0.1457	0.0120	0.0210	328.4	12.20	1.111
9	1.250	0.1029	0.0060	0.0140	321.8	8.61	1.117
10	1.500	0.0658	0.0020	0.0100	317.2	4.97	1.118
11	1.750	0.0333	0.0000	0.0080	311.5	0.00	1.126
12	2.000	0.0130	0.0000	0.0080	306.2	0.00	1.138
13	2.250	0.0038	0.0000	0.0060	304.7	0.00	1.139
14	2.500	0.0011	0.0000	0.0030	302.2	0.00	1.148
15	2.600	0.0006	0.0000	0.0020	301.8	0.00	1.149
16	2.700	0.0005	0.0000	0.0020	300.7	0.00	1.153

TABLE 34

Data for Heated Confined Jet $X/D = 29.319$

Pt#	R(cm)	CO2(msf)	DP(psi)	PT(psi)	T(K)	U(m/s)	RHO(Kg/M3)
1	0.000	0.1913	0.0260	0.0260	324.3	17.71	1.144
2	0.050	0.1913	0.0259	0.0260	324.1	17.67	1.144
3	0.100	0.1910	0.0255	0.0260	323.8	17.52	1.145
4	0.200	0.1912	0.0250	0.0250	323.1	17.33	1.148
5	0.300	0.1870	0.0240	0.0240	322.5	16.98	1.148
6	0.400	0.1840	0.0220	0.0220	321.5	16.24	1.150
7	0.500	0.1785	0.0200	0.0210	320.5	15.47	1.152
8	0.600	0.1731	0.0168	0.0200	319.5	14.17	1.153
9	0.800	0.1596	0.0150	0.0150	318.0	13.39	1.153
10	1.000	0.1425	0.0100	0.0100	316.5	10.94	1.151
11	1.200	0.1265	0.0080	0.0080	315.0	9.79	1.150
12	1.400	0.1093	0.0050	0.0051	312.0	7.73	1.154
13	1.600	0.0904	0.0030	0.0030	310.0	5.99	1.154
14	1.800	0.0740	0.0020	0.0020	308.0	4.89	1.155
15	2.000	0.0576	0.0007	0.0007	305.0	2.89	1.159
16	2.250	0.0374	0.0003	0.0003	303.0	1.89	1.159
17	2.500	0.0208	0.0001	0.0001	302.0	1.09	1.156
18	2.750	0.0092	0.0000	0.0000	301.5	0.00	1.153
19	3.000	0.0032	0.0000	0.0000	301.0	0.00	1.153
20	3.250	0.0009	0.0000	0.0000	300.1	0.00	1.155

VITA

First Lieutenant John H. Doty was born on 17 May 1958 in Syracuse, New York. He graduated from Ilion High School in 1976 and attended Clarkson University in Potsdam, New York from which he received the degree of Bachelor of Science in Chemical Engineering in May 1980. After graduation, he was employed by Hooker Chemicals and Plastics Corporation in Niagara Falls, New York until he entered Officer Training School in May 1982. After receiving his commission in the USAF, Lt Doty attended the Air Force Institute of Technology from August 1982 to March 1984 from which he obtained the degree of Bachelor of Science in Aeronautical Engineering. Upon graduation, he was employed at the Aero Propulsion Laboratory, (Fuels Branch) at the Wright-Patterson AFB, Dayton Ohio and completed requirements for the degree of Master of Science in Aeronautical Engineering on a part time basis.

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DENSITY AND CONFINEMENT EFFECTS ON MIXING
CHARACTERISTICS OF AN AXISYMMET. (U) AIR FORCE INST OF
TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI. J H DOTY

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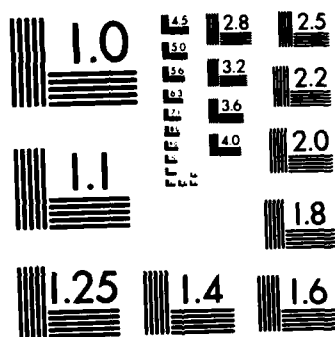
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ABSTRACT

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The effects of jet density and confinement on spreading and entrainment rate of an axisymmetrical CO_2^m jet in air, were studied. Four tests were conducted to isolate these effects: heated free jet; isothermal free jet; heated confined jet; and isothermal confined jet. The mass flow rate of CO_2^m was held constant for all tests at 6 kg/hr. Flow visualization studies were also conducted to corroborate important results.

It was determined that isokinetic sampling for CO_2^m concentrations is important for obtaining accurate measurements in the jet shear layer for axial distances less than 10 jet diameters.

An increase in velocity at the edge of the jet near the entrance plane was noted for the isothermal studies where the density difference between the jet and the surrounding air was significant.

Spreading rate for the jets was determined using the half width at half maximum criterion. In all four tests it was determined that the scalars of temperature and CO_2^m spread at the same rate, less than velocity in the initial jet regions and greater than velocity in the fully developed regions of the jet. Also, the heated jet spread slower than the isothermal jet, and the confinement imposed noticeable restrictions on the spreading and entrainment rates of the jet.

The heated jet entrained more air than the isothermal jet at the same axial location even though the heated jet had a smaller cross sectional area. In addition, the free jet entrained almost 60% more air than the confined jet. *←*

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