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Dispersion measurements in turbulent flows (boundary layer and plane jet)

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Abstract—Temperature measurements concerning dispersion of heat downstream of a steady line source located successively in a boundary layer and in a plane jet are presented and discussed. Temperature statistics obtained in these two turbulent flows are compared in a satisfactory way using a rescaling scheme based on the value of the temporal integral Lagrangian scale of the vertical velocity fluctuation at the source location. A simple diffusion model has been developed and is qualitatively in agreement with experimental results in the first phase of the diffusion process.

1. INTRODUCTION

THE PREDICTION of the dispersion of a passive contaminant in a turbulent flow is a problem of wide-ranging interest due to the importance of turbulent diffusion in heat and mass transfer problems and combustion applications. Recent papers have brought a large amount of experimental results on dispersion of passive scalars from a line source or point source located in turbulent flows. These experimental works have been mainly performed in grid generated isotropic turbulence [1, 2] or in the turbulent boundary layers [3–7]. In parallel the problem of predicting the dispersion and mixing of a passive scalar has received considerable attention from researchers using Lagrangian or Eulerian approaches [8–13].

The purpose of this paper is to present and discuss some experimental results concerning the dispersion of heat downstream of a steady line source located successively in a turbulent boundary layer and a turbulent plane jet. Detailed statistics of the temperature fluctuations are calculated by means of a simple model based on Gifford's fluctuating plume dispersion model. As shown in similar studies in the initial phase of the diffusion process the observed behaviour of temperature statistics is the result of the growth of the instantaneous plume width relative to the mean plume width.

2. EXPERIMENTAL PROCEDURE

The dispersion experiments were conducted successively in a boundary layer and in a plane jet. A schematic diagram of the two experiments is shown in Fig. 1. For the boundary layer the measurements were performed in a closed circuit wind tunnel already described in ref. [5] giving a free stream velocity of 6.9 m s^{-1}. The boundary layer thickness at the source location δ_s was 98 mm. The floor of the test section was adiabatic except downstream of the source location where a copper plate is kept equal to the free stream temperature θ_e. In the present study we are not concerned with the ground absorption phenomenon the influence of which is limited to the region close to the wall [5].

The two-dimensional jet was generated by a blower wind tunnel with a 20 : 1.08 contraction ratio leading to a slot of width b = 10.8 mm and span of 200 mm. Two confining vertical walls (2 × 0.5 m) were installed to maintain the two dimensionality of the jet. The jet velocity at the nozzle exit was maintained at 25.7 m s^{-1} [15].

The thermal line sources were nichrome or constantan wires 0.09 mm in diameter (and for some experiments 0.05 mm in diameter) tensioned laterally across the flow. The electric power was always small enough to regard heat as a passive contaminant. The maximum Reynolds number based on the 'film' temperature (average of wire and flow temperatures) was calculated to be less than 40 in all cases.

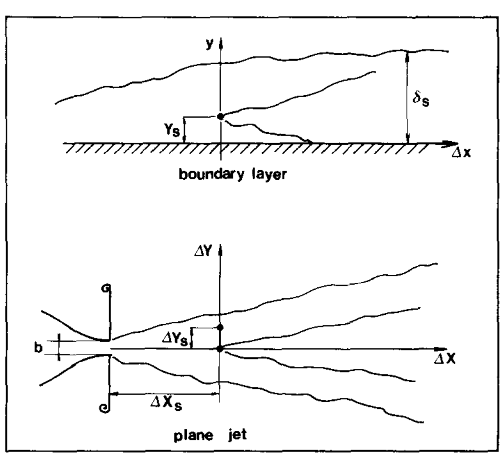


FIG. 1. Schematic diagram.

NOMENCLATURE

d_s	source wire diameter
F_θ	flatness factor of temperature fluctuations, $\overline{\theta'^4}/(\overline{\theta'^2})^2$
I_θ	intensity of temperature fluctuations, $(\overline{\theta'^2})^{1/2}/\theta_{max}$
l_L	vertical length scale, $(\overline{v'^2})^{1/2}T_L$
l_s	instantaneous plume width (standard deviation)
l_{sm}	molecular contribution to l_s
l_{st}	turbulent contribution to l_s
L_L	streamwise length scale, UT_L
L_u	distance for which $U/U_{max} = 0.5$
Q	line source strength
S_θ	skewness factor of temperature fluctuations, $\overline{\theta'^3}/(\overline{\theta'^2})^{3/2}$
T_L	temporal Lagrangian integral scale
U	mean streamwise velocity
v'	velocity fluctuation component perpendicular to the source wire and the mean flow
Δx	streamwise distance from the source wire
y	distance from the wall
$y_{0.5}$ or $\Delta y_{0.5}$	distance for which $\theta/\theta_{max} = 0.5$
y_{max} or Δy_{max}	distance for which $\theta = \theta_{max}$
Δy	distance from the jet axis.

Greek symbols

γ_θ	thermal intermittency factor
δ	99% boundary layer thickness
ε	turbulence dissipation rate
η	Kolmogoroff scale
ρ	air density
$\theta(x, y)$	mean temperature
θ_{max}	peak value
θ'	temperature fluctuation
θ_B	temperature scale
θ_s	instantaneous plume centreline temperature
σ_s	turbulent dispersion (standard deviation).

Subscripts

L	Lagrangian
s	source.

The streamwise and vertical components were measured with a constant temperature cross wire anemometer using platinum wires of diameter 5 μm and length 1.4 mm at an overheat ratio of 0.8 by T.S.I. 1050 hot-wire bridges.

Temperature fluctuations were measured with a platinum–rhodium 10% cold wire 0.7 μm in diameter operated at 0.19 mA in order to minimize the sensitivity of the wire to velocity fluctuations.

At each measurement position velocity and temperature data were stored on magnetic tape (EMI 300) for later processing on a microcomputer.

Temperature measurements were carefully corrected accounting for the thermal prong-wire interaction. This was achieved after dynamic calibration of the probe using the method proposed by Lecordier et al. [16]. With the selected probe ($l/d \sim 500$) the correction to the r.m.s. temperature could reach 11% at 10 m s^{-1}.

The characteristics of the two flows at the source location are both presented in Table 1 and in Fig. 2.

3. EXPERIMENTAL RESULTS

Mean temperature profiles are plotted in Fig. 3 for the two dispersion measurements. For the boundary layer experiment the source wire is successively located at $y_s/\delta_s = 0.075$, 0.2 and 0.4. For the plane jet experiment the source wire is located on the jet axis at a distance of $30b$ from the nozzle.

In the initial stage of the diffusion process for both

Table 1

Boundary layer	y_s/δ_s	U/U_e	$(\overline{v'^2})^{1/2}/U_e$	R_e/δ_s
	0.05	0.6	0.042	
	0.75	0.63	0.042	
$U_e = 6.9$ m s^{-1}	0.12	0.68	0.042	45 400
$\delta_s = 9.8$ cm	0.20	0.73	0.040	
	0.4	0.83	0.034	
	0.6	0.91	0.028	
Plane jet	$\Delta y_s/b$	U/U_{max}	$(\overline{v'^2})^{1/2}/U_{max}$	R_{e_b}
$U_{max_s} = 11.5$ m s^{-1}	0	1	0.198	
$b = 1.08$ cm				18 600
$x_s = 30b$	1	0.98	0.198	

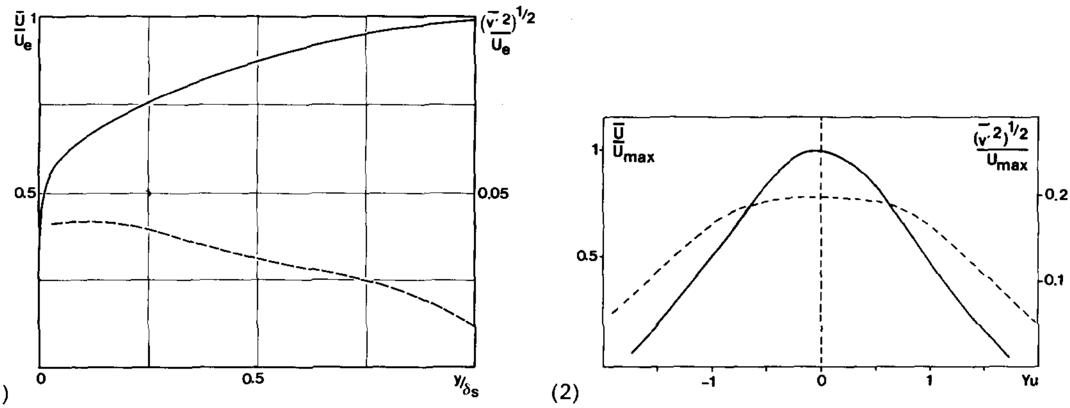


FIG. 2. Velocity measurements: 1, boundary layer; 2, plane jet.

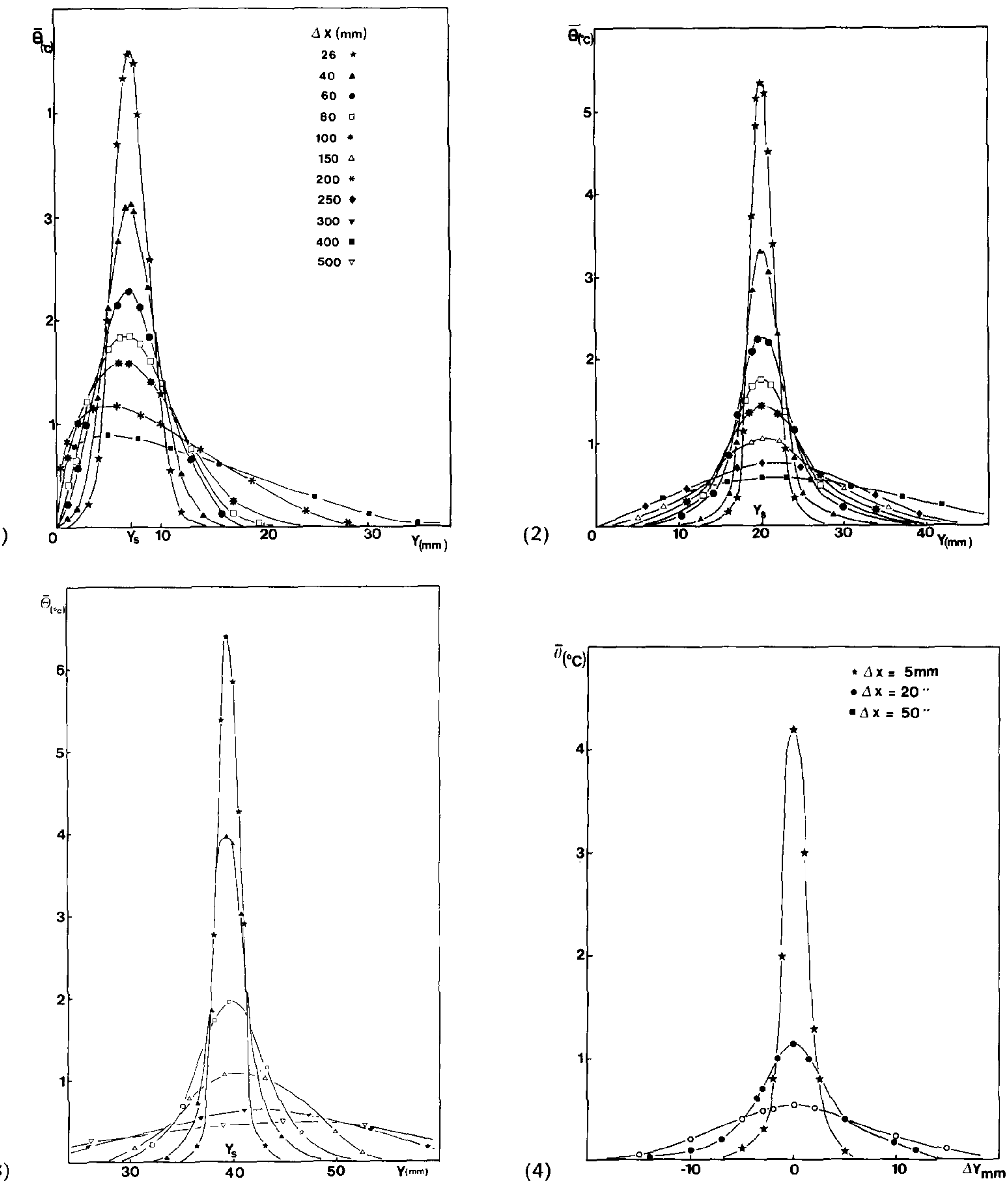


FIG. 3. Mean temperature profiles: 1, boundary layer $y_s/\delta_s = 0.075$; 2, boundary layer $y_s/\delta_s = 0.2$; 3, boundary layer $y_s/\delta_s = 0.4$; 4, plane jet $y_s = 0$.

experiments mean temperature profiles are found to be fairly symmetrical and approximately Gaussian. For the boundary layer experiment further downstream these profiles become skewed as dispersion is limited by the wall. As already mentioned in previous studies [3, 4] the characteristics of mean temperature profiles (peak value and width) are found to be very sensitive to the source location. When power laws are fitted to the θ_{max} results presented in Fig. 4, the exponent n characterizing the fall-off, ranges from -1 to -0.7 for the boundary layer experiments. For the plane jet experiment the exponent n is about -1. Results obtained in the boundary layer experiment put in evidence the difficulty of finding a unique value of n over the whole range of the diffusion process.

Profiles of the intensity of temperature fluctuations $I_\theta = (\overline{\theta'^2})^{1/2}/\theta_{max}$ are shown in Fig. 5 for three selected experiments (boundary layer $y_s/\delta_s = 0.075$ and 0.2, plane jet $\Delta y_s = 0$). I_θ is plotted vs y_θ where $y_\theta = (y - y_{max})/y_{0.5}$ and $\theta(y_{0.5}) = \theta_{max}/2$.

It is worth noting the high level of $I_\theta(\sim 100\%)$ in comparison with the results obtained in classical heat transfer problems in turbulent flows, wall heated boundary layers $I_\theta \sim 0.05$–0.10 [17], heated grid $I_\theta \sim 0.05$ [18], heated plane or round jets $I_\theta \sim 0.25$–0.35 [19]. The streamwise evolution of the maximum value of I_θ is presented in Fig. 6. A similar trend is observed for the two cases. At first $(\overline{\theta'^2})^{1/2}_{max}/\theta_{max}$ increases, reaches a maximum value and thereafter decreases. In our experiments the streamwise extent of measurements is not sufficient to conclude about the asymptotic behaviour of $I_{\theta_{max}}$.

Additional information concerning the temperature

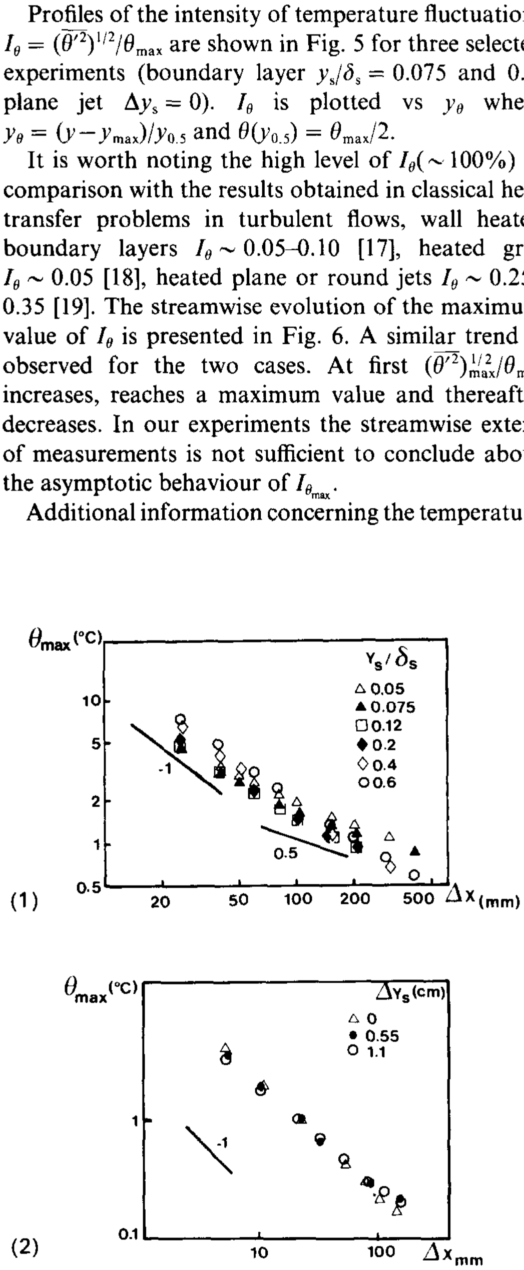


FIG. 4. Peak temperatures: 1, boundary layer; 2, plane jet.

statistics of the plane jet experiment is given in Fig. 7 where profiles of $\bar{\theta}$, $(\overline{\theta'^2})^{1/2}$, S_θ, and F_θ, are plotted at two selected sections: $\Delta x = 5$ and 20 mm.

The streamwise evolution of the skewness factor S_θ and the flatness factor F_θ determined on the source axis and shown in Fig. 8 presents a similar trend to that of $I_{\theta_{max}}(x)$ with a maximum value located at the same position that the extremum of $I_{\theta_{max}}$. The intermittency factor γ_θ defined as the proportion of time where θ is larger than θ_e has been obtained from pdf using the method proposed by Bilger et al. [20]. Results of $\gamma_\theta(0)$ determined on the source axis presented also in Fig. 8 are in agreement with the observations of Fackrell and Robins [6] and Paranthoën [21]. We can note the correspondence between the location of the maximum of $I_{\theta_{max}}(0)$ and the minimum of $\gamma_\theta(0)$.

4. RESCALING SCHEME

The need to compare results obtained for various locations of the source within the boundary layer and extend this comparison to the plane jet results have led the authors to look for a rescaling scheme.

For this purpose several schemes have been previously suggested in order to rescale data obtained in turbulent boundary layer diffusion experiments.

In their pioneering work concerning the diffusion downstream of a ground level line source Poreh and Cermak [22] point to the fact that in the intermediate zone where the diffusing plume is submerged in the boundary layer the mean concentration profiles can be renormalized using the peak value θ_{max} and $y_{0.5}$ the distance for which $\bar{\theta}/\theta_{max} = 0.5$. However, for the case of elevated sources the longitudinal evolution of θ_{max} and $y_{0.5}$ is found to be very dependent on the source distance from the wall [3, 4]. Consistent with surface layer similarity Raupach and Legg [7] use the temperature scale θ_* defined by

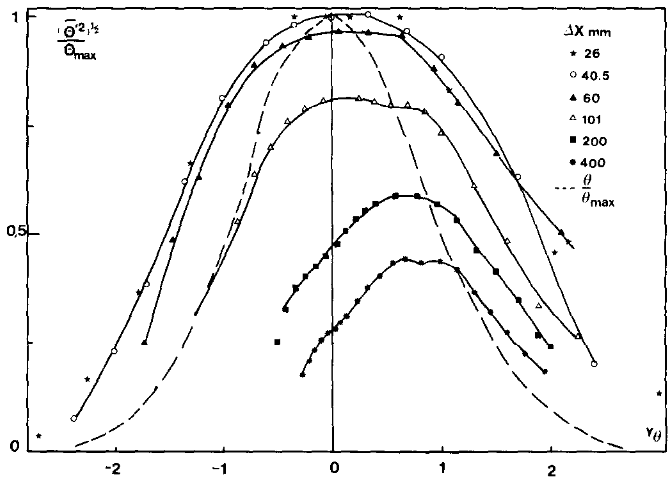
$$\theta_* = \frac{Q}{\rho C_P U(y_s) y_s}$$

and the source height y_s to rescale the streamwise distance from the source location.

The need to compare dispersion measurements issued from several turbulent flows has led the authors to look for a more general rescaling scheme based on the value of the Lagrangian time scale of the vertical velocity fluctuations T_L at the source location.

This rescaling scheme is linked to a simple model of the temperature field downstream of the line source. Close to the source as shown in Fig. 9 the temperature field consists of an instantaneous thin waving plume. As in the fluctuating plume model of Gifford [23] the temperature profile within the instantaneous plume is assumed to have a Gaussian shape characterized by its peak value θ_s and its standard deviation l_s. Now if the dispersion process is averaged over a time large in comparison with the integral time scale of the flow we obtain a mean plume. The temperature profile within

(1)



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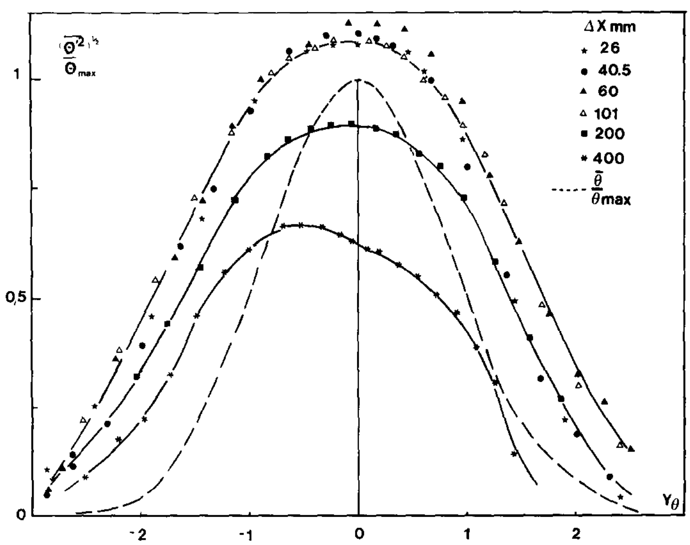

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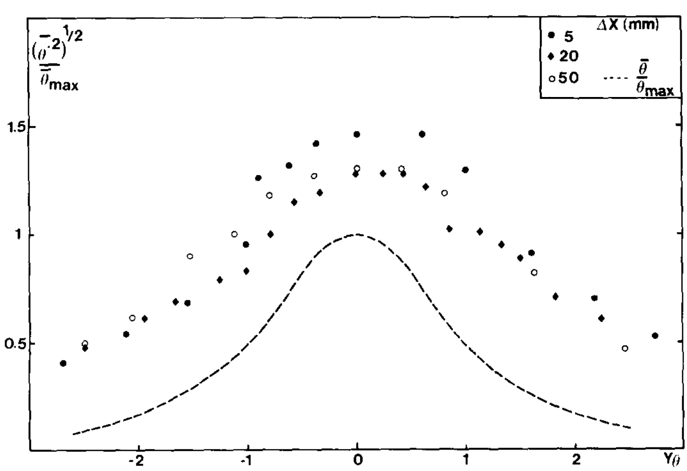

FIG. 5. Intensity of temperature fluctuation profiles: 1, boundary layer $y_s/\delta_s = 0.075$; 2, boundary layer $y_s/\delta_s = 0.2$; 3, plane jet $y_s = 0$.

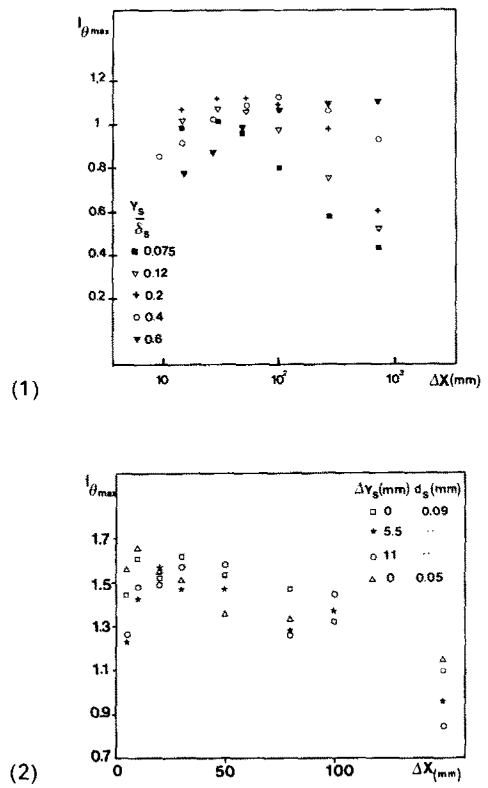

FIG. 6. Relative intensity $I_\theta(x)$: 1, boundary layer; 2, plane jet.

the mean plume is assumed also to have a Gaussian shape characterized by its centreline value θ_{max} and its standard deviation $(\sigma_s^2+l_{sm}^2)^{1/2}$. σ_s is the standard deviation characterizing the turbulent dispersion and l_{sm} is an additional term due to molecular diffusion. It is worth noting that except close to the source wire we always have $\sigma_s \gg l_{sm}$.

Close to the source wire the direction of the instantaneous plume is almost exclusively dependent on the value of the vertical velocity fluctuation at the source

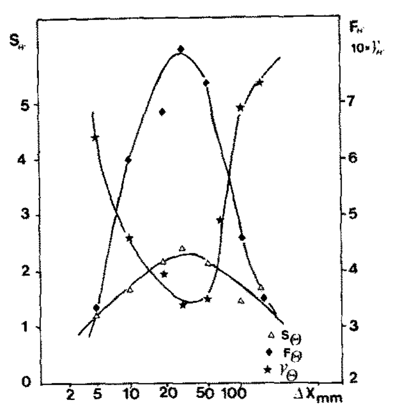

FIG. 7. Temperature statistics (plane jet $y_s = 0$).

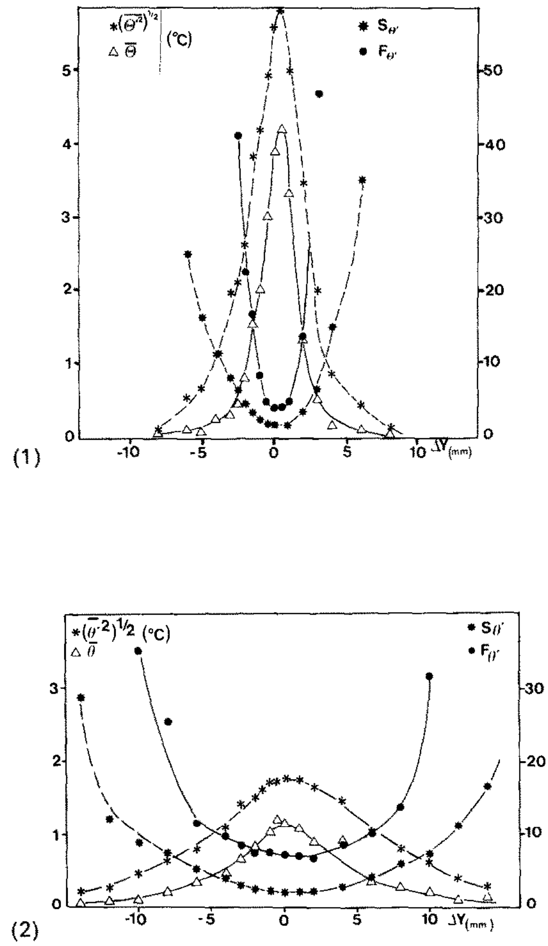

FIG. 8. Temperature statistics profiles (plane jet $y_s = 0$): 1, $\Delta x = 5$ mm; 2, $\Delta x = 20$ mm.

location. Thus the instantaneous plume keeps on average the same direction over a distance $l_2 = U\tau_2$ where τ_2 is the Eulerian temporal integral scale of the vertical velocity fluctuation at the source location. Now if we take a small part of the instantaneous plume and adopt a Lagrangian point of view this element keeps on average the same direction over a distance $L_L = UT_L$ where T_L is the Lagrangian time-scale of the vertical velocity fluctuation.

The behaviour of the mean plume width σ_s is given by Taylor's theory [24]

$$\frac{\Delta x}{L_L} \ll 1, \quad \sigma_s = l_L \frac{\Delta x}{L_L} \tag{1}$$

$$\frac{\Delta x}{L_L} \gg 1, \quad \sigma_s = \sqrt{2} l_L \left(\frac{\Delta x}{L_L}\right)^{1/2} \tag{2}$$

where

$$l_L = (\overline{v'^2})^{1/2} T_L . \tag{3}$$

If we are interested in the behaviour of the mean plume we can write at any section downstream of the

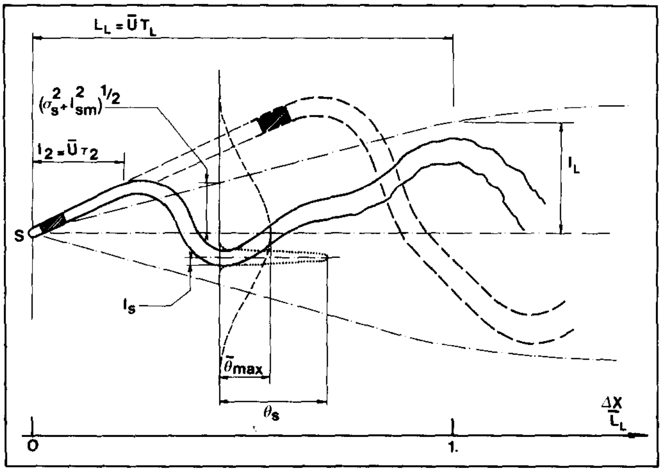

FIG. 9. Mean and instantaneous plume.

line source a heat conservation relation

$$Q = \rho C_P \int_{-\infty}^{\infty} U\theta \, dy$$

$$= \rho C_P \theta_{max}(\Delta x)\sigma_s(\Delta x) \int_{-\infty}^{\infty} U \frac{\theta}{\theta_{max}} \, d\,(y/\sigma_s). \quad (4)$$

If the mean plume width is small regardless of the homogeneity length of the mean velocity profile $(\sigma_s/U)(\partial U/\partial y) \ll 1$) and if the mean temperature profiles are self similar with a Gaussian shape, relation (4) leads to

$$Q = \sqrt{(2\pi)}\rho C_P \theta_{max}(\Delta x)\sigma_s(\Delta x)U(y_s, \Delta x). \quad (5)$$

By selecting the particular section where $\Delta x = L_L$ we can define a temperature scale θ_B

$$\theta_B = \frac{Q}{\sqrt{(2\pi)}\rho C_P l_L U(y_s, \Delta x = L_L)}. \quad (6)$$

From these considerations we can expect a better presentation of the experimental results relative to the mean temperature field by means of a length scale L_L and a temperature scale θ_B.

For turbulent flows, values of U and $(\overline{v'^2})^{1/2}$ are usually known and T_L is the only unknown quantity variable in relation (6).

Previous measurements realized in turbulent boundary layers [21, 25] have shown that $T_L(y_s)$ can be reasonably approximated by the relation given by Picart [26]

$$T_L(y_s) = \frac{0.2\overline{v'^2}(y_s)}{\varepsilon(y_s)} \quad (7)$$

where $\varepsilon(y_s)$ is the turbulence dissipation rate at the source location.

For an example values of L_L and l_L are presented in dimensionless form in Fig. 10. For the boundary layer case Dupont *et al.* [27] have shown that L_L can be given by

$$\frac{L_L}{\delta_s} = 7.5\left(\frac{y_s}{\delta_s}\right)^{1.5} \quad \text{with} \quad 0.05 < \frac{y_s}{\delta_s} < 0.6. \quad (8)$$

It is worth noting that the experimental value of T_L deduced from the streamwise evolution of $\overline{(y-\bar{y})^2}(\Delta x)$ can be assimilated to a pseudo-Lagrangian characteristic of the flow.

At this point, measurements of the Lagrangian time-scale T_L are not available for the turbulent plane jet. Under these circumstances our strategy for this flow is to calculate T_L from relation (7) by using velocity dissipation measurements performed by Gutmark and Wygnanski [28] in a similar flow. Longitudinal evolution of calculated values of L_L and l_L is presented in Fig. 11 for the case of the turbulent plane jet. It is worth noting that L_L is approximately constant for this flow when $\Delta x/b > 30$ and is about $15b$ on the jet axis.

As for the turbulent boundary layer, L_L and l_L

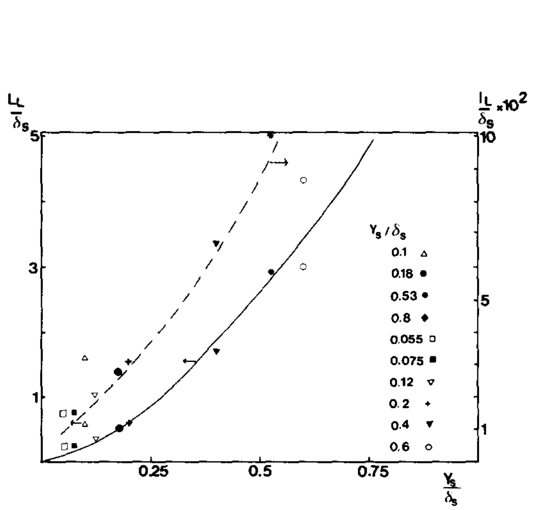

FIG. 10. Evolution of L_L and l_L (boundary layer).

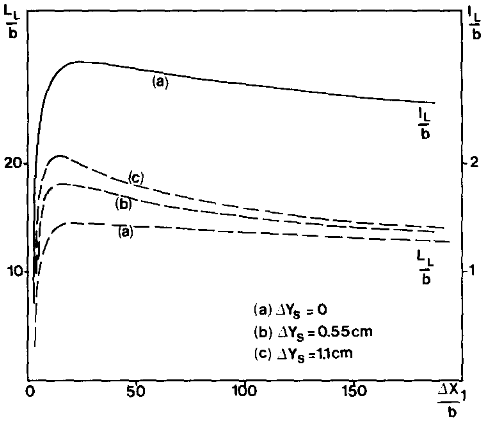

FIG. 11. Evolution of L_L and l_L (plane jet).

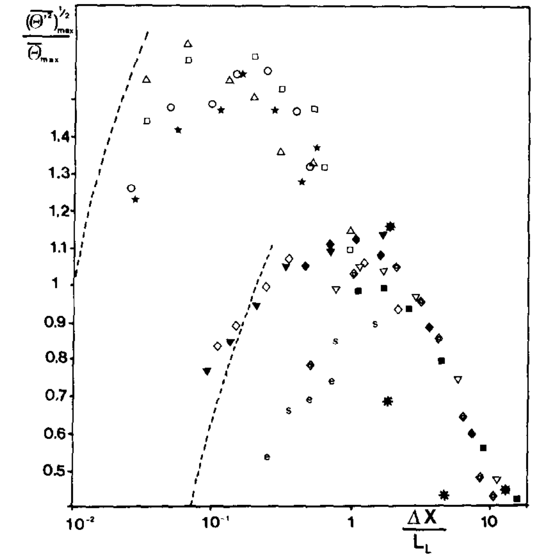

FIG. 13. Dimensionless evolution of $I_{q_{max}}$.

are found to be slightly dependent on the streamwise position allowing a simple rescaling scheme of the diffusion process with constant length scales calculated at the source location.

By using the scheme described above, the temperature peak θ_{max} normalized with the temperature scale θ_B has been plotted in Fig. 12 as a function of $\Delta x/L_L$. The data issued from experiments performed in the two turbulent flows gather approximately on a single curve regardless of the source location. Results from similar dispersion experiments have been plotted in the same figure. A power law can be fitted to θ_{max}/θ_B data as a function of $\Delta x/L_L$ when $\Delta x/L_L < 0.5a$ -1 powerfall is observed while when $\Delta x/L_L > 5$ the power is about -0.5 in agreement with Taylor's theory. This good agreement is satisfactory considering the large sensitivity of the longitudinal evolution of the peak temperature with the source location mentioned in the previous section. However, this good agreement is not obtained when this rescaling scheme is applied to the relative intensity $(\overline{\theta'^2})^{1/2}_{max}/\theta_{max}$.

As shown in Fig. 13 significant differences are found between results issued from experiments realized in various kinds of turbulent flow.

5. MODEL

In order to explain these discrepancies the diffusion model presented in the previous section has been used in order to calculate the temperature signal detected by the temperature probe.

A crude approximation of actual temperature signals in the first part of the diffusion process can be achieved by considering (Fig. 14) Gaussian temperature pulses of amplitude θ_s [29]. The thermal intermittency factor of such signals is defined as $\gamma_\theta = t_s/T$ where t_s is the width and T is the period of temperature signals. The definition of γ_θ is linked to a threshold level θ_T which can be characterized for Gaussian pulses by $n = \sqrt{(2 \ln (\theta_s/\theta_T))}$.

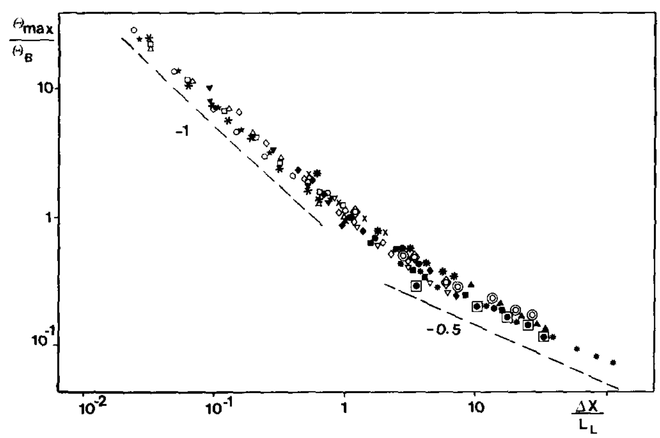

FIG. 12. Dimensionless evolution of peak temperatures.

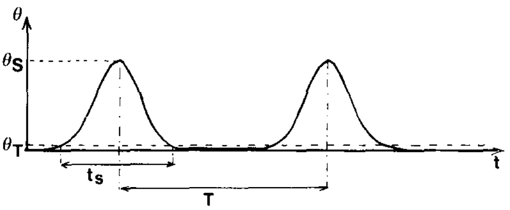

FIG. 14. Example of temperature fluctuations.

The temperature statistics can then be calculated as a function of θ_s, γ_θ and n

$$\bar{\theta} = \frac{\gamma_\theta}{2n}\sqrt{(2\pi)}\,\mathrm{erf}\left(\frac{n}{\sqrt{2}}\right)\theta_s \tag{9}$$

$$\overline{\theta^2} = \frac{\gamma_\theta}{2n}\sqrt{(2\pi)}\frac{\mathrm{erf}\,(n)}{\sqrt{2}}\theta_s^2 \tag{10}$$

$$\overline{\theta^p} = \frac{\gamma_\theta}{2n}\sqrt{(2\pi)}\frac{\mathrm{erf}\,(n\sqrt{(p/2)})}{\sqrt{p}}\theta_s^p. \tag{11}$$

Use of the heat conservation equation for the instantaneous plume and for the mean plume leads to

$$\theta_s l_s = \theta_{\max}(\sigma_s^2 + l_{sm}^2)^{1/2} \sim \theta_{\max}\sigma_s. \tag{12}$$

In particular γ_θ and I_θ on the source axis can be calculated from expressions (9), (10) and (12) and can be written as

$$\gamma(0) = \frac{2n}{\mathrm{erf}\,(n/\sqrt{2})\sqrt{(2\pi)}}\frac{l_s}{\sigma_s} \tag{13}$$

$$I_\theta(0) = \left\{\frac{\mathrm{erf}\,(n)}{\mathrm{erf}\,(n/\sqrt{2})}\frac{1}{\sqrt{2}}\frac{\sigma_s}{l_s} - 1\right\}^{1/2}. \tag{14}$$

Hence the evolution of statistics of the plume in the initial stage of the diffusion process is the result of the growth of the instantaneous plume width relative to the mean plume width.

For $n > 2$ [erf (n)/erf $(n/\sqrt{2})$] ~ 1 and relation (15) given by Lumley and Van Cruyningen [30] is found again

$$I_\theta(0) = \left(\frac{1}{\sqrt{2}}\frac{\sigma_s}{l_s} - 1\right)^{1/2}. \tag{15}$$

The streamwise evolution of σ_s is given by Taylor's theory while the increase of the instantaneous plume width results from three effects.

(1) The size of the source characterized by the wire diameter d_s.

(2) The effect of molecular diffusion characterized by l_{sm} with

$$l_{sm}^2 = 2a_g\Delta t. \tag{16}$$

(3) The effect of turbulence when the instantaneous plume width l_s is larger than the Kolmogoroff scale η. This effect is characterized by l_{st}.

By simply assuming independence between the molecular and turbulent contribution in the first phase of the dispersion process, where σ_s grows as Δx, the temperature intensity I_θ is given by

$$I_\theta = \left\{\frac{1}{\sqrt{2}}\frac{\Delta x/L_L}{\left(\frac{d_s^2}{l_L^2} + \frac{2}{Pe_D}\frac{\Delta x}{L_L} + \frac{l_{st}^2}{l_L^2}\right)^{1/2}} - 1\right\}^{1/2} \tag{17}$$

where

$$Pe_D = \frac{(\overline{v'^2})^{1/2} l_L}{a_g}$$

is the diffusion Peclet number. As already mentioned by Durbin [8] this relation puts in evidence the strong influence of the ratio d_s/l_L on the initial behaviour of I_θ.

When $l_s \ll \eta$ $l_{st} = 0$ and relation (17) can be written as

$$I_\theta = \left\{\frac{1}{\sqrt{2}}\frac{\Delta x/L_L}{\left(\frac{d_s^2}{l_L^2} + \frac{2}{Pe_D}\frac{\Delta x}{L_L}\right)^{1/2}} - 1\right\}^{1/2}. \tag{18}$$

It is worth noting that the dashed lines corresponding to relation (18), plotted in Fig. 13 appear as the asymptotic initial behaviour of I_θ. Characteristics of the diffusion experiments (d_s/l_L, Pe_D, d_s/η, ...) have been gathered in Table 2 and show that in our experiments the condition $l_s \ll \eta$ is never satisfied.

Further prediction concerning the behaviour of I_θ requires the knowledge of evolution of l_{st} whatever time. Unfortunately our knowledge of the properties of l_{st} is only confined to a limited phase of the diffusion process. When relative diffusion is dominated by eddies in the inertial subrange (assuming that the turbulence Reynolds number is high enough) the instantaneous plume width will grow according to Richardson's law [31]

$$l_{st}^2 = \alpha_{RI}\varepsilon\Delta t'^3 \tag{19}$$

where $\Delta t'$ is the time elapsed from an effective time origin for this inertial subrange dominated phase.

The lack of information concerning the behaviour of l_{st} for the whole phase of the diffusion process leads us to a qualitative explanation of the streamwise evolution of I_θ in line with equation (17).

As shown in Fig. 15 the initial increase of I_θ and decrease of γ_θ are related to the molecular dominated phase of l_s. In a second phase where l_s is larger than the Kolmogoroff scale, l_s increases at the same rate as σ_s and I_θ and γ_θ present an extremum. Then the strong increase of l_{st} due to turbulence leads to a decrease of the ratio σ_s/l_s. In this phase I_θ decreases and γ_θ increases.

This description is in agreement with measurements presented in Fig. 6.

Finally we have calculated from thermal intermittency factor measurements realized in the plane jet experiment, the values of l_s/l_L and l_s/η using relation (13) [35].

Table 2

References	δ_s (cm)	U_e (cm s^{-1})	$d_s \times 10^3$ (cm)	y_s/δ_s	L_L (cm)	l_L (cm)	$(\overline{v'^2})^{1/2} l_L/\nu_g$	d_s/l_L	d_s/η_s	Symbols
Boundary layer										
Shlien and Corrsin [3, 36]	5.15	1270	1.27	0.24	4.43	0.19	65	0.007	0.1	✸
			12.7					0.07	1	◎
	5.15	1270	1.27	0.62	17.8	0.65	189			
			12.7							
Raupach and Legg [7]	54	1100	90	0.11	14.58	1.13	330	0.08	5.3	◈
Paranthoën [21]	0.85	2850	10	0.1	0.9					▲
	0.85	2850	10	0.18	0.48					▣
	0.85	2850	10	0.53	2.46	0.08	45.6	0.125	2	✸
	0.85	2850	10	0.8	4.52					x
Sbaibi [33]	9.8	690	26	0.2	5.9	0.304	58.5	0.09	1.2	s
Present work	9.8	690	10	0.055	2.25	0.145	28	0.007	0.62	●
	9.8	690	10	0.075	2.45	0.147	29	0.07	0.6	■
	9.8	690	10	0.12	3.43	0.206	40	0.05	0.5	▽
	9.8	690	10	0.2	5.9	0.304	58.5	0.033	0.45	◆
	9.8	690	10	0.4	16.9	0.65	109	0.015	0.35	◇
	9.8	690	10	0.6	29.4	0.84	115	0.012	0.3	▼

References	$\Delta x_s/b$	U_e (cm s^{-1})	$d_s \times 10^3$ (cm)	$\Delta y_s/b$	L_L (cm)	l_L (cm)	$(\overline{v'^2})^{1/2} l/\nu_g$	d_s/l_L	d_s/η_s	Symbols
Plane jet										
Present work	30	1150	9	0	15.72	3.14	4847	0.0029	19	□
	30		9	0.51	19.12	3.82	5794	0.0024	19	★
	30		9	1.02	21.11	4.22	6089	0.0022	19	○
			5	0	15.72	3.14	4847	0.0016	0.9	*
	60	760	9	0	15.72	3.14	3203	0.0023	1.1	△

References	D (cm)	U_e (cm s^{-1})	$d_s \times 10^3$ (cm)	$\Delta y_s/D$	L_L (cm)	l_L (cm)	$(\overline{v'^2})^{1/2} l_L/\nu_g$	d_s/l_L	d_s/η_s	Symbols
Pipe flow										
Crum and Hanratty [34]	7.62	254	32	0	19.8	0.71	44	0.045	0.8	e

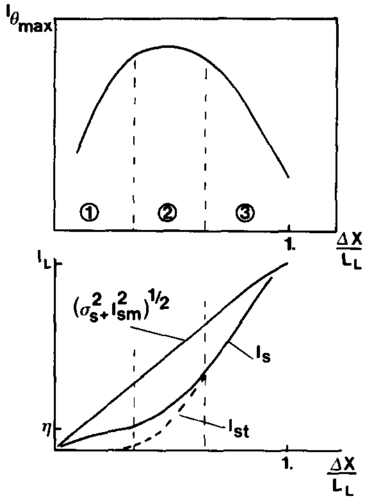

FIG. 15. Relation between σ_s, l_s and I_θ.

Results presented in Fig. 16 show that in a first phase l_s/l_L grows as $(\Delta x/L_L)^{3/4}$. The value of the exponent proves that this phase is not dominated by the molecular diffusion phenomenon in relation with the value of $d_s/\eta \sim 10$ in this zone. Then, when $l_{st} \sim l_s$ we find an inertial subrange dominated phase where l_s grows as $(\Delta x/L_L)^{3/2}$. This phase ranges from $l_s/\eta = 10$ up to at least $l_s/l_L = 0.2$. Within this phase we have $\eta \ll l_s \ll l_L$ and this situation can be related to the large value of the diffusion Reynolds number $Re_D = (\overline{v'^2})^{1/2} l_L/v_g$ of approximately 4500 in the plane jet experiment. Furthermore, in this phase $l_s^2 = \alpha_{RI}\varepsilon\Delta t'^3$ with $\alpha_{RI} \sim 0.3$ in agreement with the value given by Larcheveque [32].

Following Csanady [37] relation (19) can be rewritten as

$$\frac{l_{st}}{l_L} = (0.06)^{1/2}\left(\frac{\Delta x}{L_L}\right)^{3/2}.$$

The condition $l_{st} \ll l_L$ can only hold as long as $\Delta x/L_L$ is small compared to 2.5. Experimentally the

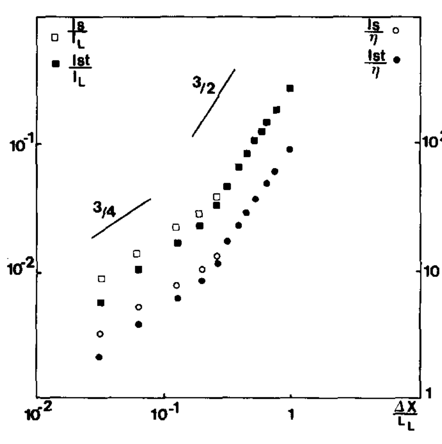

FIG. 16. Evolution of the instantaneous plume width (plane jet $y_s = 0$).

total length of this 'explosive' phase is about $0.8L_L$ in good agreement with the above prediction.

6. CONCLUSION

Measurement of mean and fluctuating temperatures have been performed downstream of the same line source located successively in two turbulent flows (boundary layer and plane jet).

Temperature statistics obtained in these experiments can be compared in a satisfactory way using a rescaling scheme based on the value of the temporal integral Lagrangian scale of the vertical velocity fluctuation at the source location. By using this scheme mean temperature data can be collapsed satisfactorily onto a simple curve.

Differences found between the evolution of intensity of temperature fluctuation measurements in the two experiments have been related to the effect of the source size characterized by the ratio d_s/l_L and to the effect of turbulence on the width of the instantaneous plume.

A simple model deduced from Gifford's model has been developed and is qualitatively in agreement with experiment results in the first phase of the diffusion process.

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MESURES DE DIFFUSION DANS DES ECOULEMENTS TURBULENTS (COUCHE LIMITE ET JET PLAN)

Résumé—Des mesures de température ont été réalisées en aval d'une source linéaire de chaleur placée successivement dans une couche limite turbulente et dans un jet plan turbulent. Les caractéristiques statistiques du champ thermique obtenues dans ces deux écoulements sont comparées de façon satisfaisante en utilisant un schéma de normation lié à la valeur de l'échelle intégrale temporelle Lagrangienne de la fluctuation verticale de vitesse au niveau de la source. Un modèle de diffusion a été développé et est en bon accord avec les résultats expérimentaux dans la première phase du processus de diffusion.

DISPERSIONS-MESSUNGEN IN TURBULENTEN STRÖMUNGEN (GRENZSCHICHT UND EBENER STRAHL)

Zusammenfassung—Es werden Temperaturmessungen vorgestellt und diskutiert, die sich mit dem Wärmeübergang stromab einer feststehenden Linienquelle beschäftigen, welche sich nacheinander in einer Grenzschicht und in einem ebenen Strahl befindet. Das statistische Verhalten der Temperatur in diesen beiden turbulenten Strömungen wird in befriedigender Weise unter Benutzung eines Verfahrens verglichen, das auf dem Wert der zeitlich integrierten Lagrange-Skala für die vertikalen Geschwindigkeitsschwankungen am Quellpunkt beruht. Es wurde ein einfaches Diffusionsmodell entwickelt, welches qualitativ gute Übereinstimmung mit experimentellen Ergebnissen der ersten Phase der Diffusionsprozesse erzielt.

ИЗМЕРЕНИЯ ДИСПЕРСИИ В ТУРБУЛЕНТНЫХ ПОТОКАХ (ПОГРАНИЧНЫЙ СЛОЙ И ПЛОСКАЯ СТРУЯ)

Аннотация—Рассматриваются результаты измерений температуры вниз по потоку от стационарного линейного источника тепла, помещаемого в пограничный слой, а затем в плоскую струю. С использованием перенормировки масштаба, основанной на интегральном масштабе Лагранжа для вертикальной флуктуации скорости в месте расположения источника, проведено сравнение температурных статистических распределений в этих двух турбулентных потоках и получено их удовлетворительное соответствие. Разработанная простая модель диффузии качественно согласуется с экспериментальными результатами в первой фазе процесса диффузии.