Determination of concentration fluctuations within an instantaneous puff

Wind tunnel experiments

Cierco\textsuperscript{1} F.-X., Soulhac\textsuperscript{1} L., Méjean\textsuperscript{1} P., Armand\textsuperscript{2} P., Salizzoni\textsuperscript{1} P.

\textsuperscript{1} Université de Lyon, \textsuperscript{2} CEA-DAM
Introduction

• The question of short or instantaneous releases is of special interest for:
  • Accidental or deliberate release in industrial or urban areas
  • Transport of hazardous materials
Introduction

• Short release dispersion requires specific attention:
  • The concentration distribution is the result of a single realization (not an ensemble average)
  • Necessity to estimate the 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd}… moments of the concentration distribution
  • With the followings restrictions:
    • Operational purposes require short computation times
    • Few available data to feed the models

• Design wind tunnel experiments so as to:
  • Characterize concentrations statistics for short releases
  • Develop a theoretical framework for an operational dispersion model: SIRANERISK, Soulhac et al., 2007 in Cambridge
Description of a short term release

• The turbulent nature of the flow induces a particular behavior for each release
• Operational dispersion models are limited to statistic approaches
Instantaneous and mean puff

At a given time $t$
Concentration variability

Variability due to the displacement of the puff centre

Variability due to internal fluctuations
Theoretical background – Experimental setup – Main results - Conclusions

**Instantaneous puff descriptors**

\[
p(C_{x/m}, x, y, z, t) = \frac{k^n}{\pi \sigma_x \sigma_y \sigma_z} \exp \left(-\frac{1}{2} \left( \frac{(x-x_c)^2}{\sigma_x^2} + \frac{(y-y_c)^2}{\sigma_y^2} + \frac{(z-z_c)^2}{\sigma_z^2} \right) \right)
\]

\[
p(C; x, y, z, t) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} p(C_{x/m}, x, y, z, t) \, dx \, dy \, dz
\]

**Conclusions**
Derivation of equations

- \( c_r(x,y,z,t) \)

\[
\overline{c_r}(x,y,z,t) = \frac{M(x_0, y_0, z_0, t_0)}{(2\pi)^{3/2} \sigma_{x,r} \sigma_{y,r} \sigma_{z,r}} e^{-\frac{1}{2} \left[ \frac{(x-x_c)^2}{\sigma_{x,r}^2} \right] - \frac{1}{2} \left[ \frac{(y-y_c)^2}{\sigma_{y,r}^2} \right] - \frac{1}{2} \left[ \frac{(z-z_c)^2}{\sigma_{z,r}^2} \right] = c_{r,0} e}
\]

- Yee and Wilson (2000):

\[
\overline{C^n_r}(x,y,z,t) = \frac{\left[ \frac{1}{k^n} \Gamma \left( \frac{n+k}{2} \right) \Gamma \left( \frac{k}{2} \right) \right]^{1/2}}{(1+ nM_x)(1+ nM_y)(1+ nM_z)} e^{-\frac{1}{2} \left[ \frac{x^2}{\left(1+ nM_x \sigma_{x,r}^2 / n \right)} \right] - \frac{1}{2} \left[ \frac{y^2}{\left(1+ nM_y \sigma_{y,r}^2 / n \right)} \right] - \frac{1}{2} \left[ \frac{z^2}{\left(1+ nM_z \sigma_{z,r}^2 / n \right)} \right] = c_{r,0} e}
\]

- 2 physical parameters:

\[
M_i = \frac{\sigma_{m,i}^2}{\sigma_{r,i}^2} \quad k = \frac{1}{i_r^2} = \frac{\sigma_{2,0}^{2,i}}{\sigma_{C_r}^2} \quad \frac{\sigma_{2,0}^{2,i}}{\sigma_{2,0}^{2,i}} = \frac{\left(1+ nM_i \right)}{n \left(1+ M_i \right)} \leq 1
\]
Experiment design

- Atmospheric wind-tunnel (Ecole Centrale de Lyon)

- Experimental setup
Instantaneous and mean puff
Experimental campaigns

- 2 stationary releases campaigns with $H_s = 20$ mm
- 1 instantaneous releases campaign with $H_s = 20$ mm
- 1 stationary release campaign with $H_s = 50$ mm
- 1 instantaneous releases campaign with $H_s = 50$ mm
Experimental process

- Instantaneous Puff $B_i: C_i(t), T_i, \sigma_i$
- $N_b$ different releases $\Rightarrow \langle T_i \rangle, \langle \sigma_i^2 \rangle, \sigma_T$
- Mean Puff $B_{moy}: C_{moy}(t), \sigma_C(t), T_{Bmoy}, \sigma_{Bmoy}$
Main results

- Averaged time arrival of each release (moy[T(j)]) and time arrival of the mean puff (T_Bmoy); R50

\[ X = 2000 \text{ mm} ; Z = 60 \text{ mm} \]
Main results

- Averaged time arrival of each release ($\text{moy}[T(j)]$) and time arrival of the mean puff ($T_{\text{Bmoy}}$); R20

\[ y = 0.4003x + 0.1313 \]
\[ R^2 = 0.9999 \]
Mean results

- Mean and relative puff variances, (Var_Bmoy, Var-r = moy[Var(j)]), mass center spread variance (Var_m = Var_tj.)
- R50

Theoretical background – Experimental setup – Main results - Conclusions
Mean results

• Mean and relative puff variances, \((\text{Var}_B\text{moy}, \text{Var}_r = \text{moy[Var(j)]})\), mass center spread variance \((\text{Var}_m = \text{Var}_t_j.)\); 

\[ R20 \]
Experimental process

- Y transverse direction: C*t (Y) and other moments

\[ \frac{\sigma^2_{\text{tot},i} \left[ n \right]}{\sigma^2_{\text{tot},i}} = \frac{1 + nM_i}{n(1 + M_i)} \leq 1 \]
Main Results

- Gaussian distribution of the time integrated distribution (which same std as the mean puff)
Experimental process

- Y transverse direction: $C^*t$ (Y) and other moments
Mean results

- Y-puff mean spread std for steady and unsteady releases (R20/R50)
Main results

• Comparison of Y-relative spread std longitudinal evolution (R20/R50)
Main results

- Compulsed data for a sensor position (R50, X= 4 m)

<table>
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<tr>
<th>$S_{tot,y}$</th>
<th>$M_y$</th>
<th>$S_{r,y}$</th>
<th>$S_{m,y}$</th>
<th>$S_{tot,x}$</th>
<th>$M_x$</th>
<th>$S_{r,x}$</th>
<th>$S_{m,x}$</th>
<th>$I(y)$</th>
<th>$I_r$</th>
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<td>0.26 m</td>
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<td>0.46 m</td>
<td>0.14 m</td>
<td>0.57</td>
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Conclusions

- Specific experiment designed for short releases
- Main results:
  - Longitudinal dispersion dominated by relative spread
  - Longitudinal characteristics do not depend on Y
  - Plume and puff mean spreads are equivalent in the transverse direction
  - The methodology allows for the determination of the different physical involved parameters: i and M
- Application:
Perspectives

- Simulations and wind-tunnel experiments of short releases on an idealised district
- Integration of a variability model in operational dispersion models (SIRANERISK)

Thank you for your attention
Experimental results

- 2 instantaneous puffs, mean puff, and idealized instantaneous puff ($X = 2000$ mm, R0)
Main Results

- Comparison of X-meandering ratio longitudinal evolution (R20/R50)
Gaussian puff descriptors

- $\sigma_{r,i} = g(t)$
- $\sigma_{m,i} = h(t)$
- $C(x,y,z,t)$

Idealized Puff in an uniform flow

Puff deformation in a shear layer

$$p_{m,3D}(x_c, y_c, z_c) = \frac{1}{(2\pi)^{3/2} \sigma_{x,m} \sigma_{y,m} \sigma_{z,m}} \exp \left( - \frac{1}{2} \frac{x_c^2}{\sigma_{x,m}^2} \right) \exp \left( - \frac{1}{2} \frac{y_c^2}{\sigma_{y,m}^2} \right) \exp \left( - \frac{1}{2} \frac{z_c^2}{\sigma_{z,m}^2} \right)$$