MODITIC
Modelling the dispersion of toxic industrial chemicals in urban environments

MODITIC wind tunnel experiments

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Test prediction methods for dense gas emissions in conditions of increasing complexity.
Wind tunnel work addresses dispersion processes for steady emissions
finite duration emissions

Strategy

Select operating conditions that generate strong dense gas effects – upwind spread, rapid near-field lateral spread, reduced vertical spread – rather than model specific scenarios.

Limited by choice of dense gas, carbon dioxide, for wind tunnel work.
Six categories of increasing complexity

1. Flat surface
2. Two-dimensional hill
3. Two-dimensional back-step
4. Simple array of obstacles
5. Complex array of obstacles
6. Urban area (central Paris)

Purpose
- to provide data to test computational methods
  at model scale
  at equivalent full scale
- to provide insight
1. Flat Surface

Data-base compiled from previous EnFlo work

- PERF dense gas studies, reported in Atmos Environ, 2001
- DYCE inverse modelling, reported in Boundary Layer Met., 2012
EnFlo

Twin fans

Chilled water supply ~ 10°C

Heat exchanger

Cooled rough wall ~ 15°C

Turntable

Mechanical simulation devices & rough wall

20 x 3.5 x 1.5 m working section

0 - 4 m/s

Inlet and heater section

15 layers 400 kW capacity ambient to ~ 80°C

Source

Flow control system

Gas supplies

LDA, PIV, hot wire, cold wire, web-cams etc

Computer control, data collection & data analysis

Traverse and turntable control

Speed control

Thermocouple system

Fast FFID system

Heater control

National Centre for Atmospheric Science
EnFlo

Provide full and joint concentration (FFID) and velocity fields (LDA) for continuous and unsteady releases of air or carbon dioxide (or mixtures of the two) from ground level sources.
EnFlo inflow

Neutral boundary layer generated in standard manner - vorticity generators (Irwin spires) and surface roughness.

Profiles provided of mean velocity, turbulent stresses and length scales.

Summary
boundary layer depth, $H = 1$ m
friction velocity, $u^* = 0.055 U_{ref}$
surface roughness length, $z_o = 0.088$ mm.
Similarity conditions

Reynolds numbers - surface and building constraints met.

Scaling of buoyant plume dynamics implies similarity of the emission density ratio, the emission velocity ratio and the Richardson number.

\[
u = \frac{u_*}{u_*} = \frac{U_{\text{ref}}}{U_{\text{ref}}} = \left(\frac{h_{fs}}{h_m}\right)^{1/2} = \frac{1}{2}
\]
2. Two-dimensional hill

- Shape scaled from WALLTURB ‘bump’ - designed to generate a small separation bubble on the downwind face - previous LES flow simulations in WALLTURB.

![Diagram showing two-dimensional hill with dimensions and labels: 1.377 m length, 0.835 m height, grid points, gas supply, Cylinders packed with 3 mm diameter beads and covered by a mesh, ~14 m from working section inlet.]

- ~14 m from working section inlet
Two-dimensional hill – experiment design

Experiment design.

Examination of similarity behaviour.

Example for air emissions

\[ x = 1.385, \]
\[ x_s = 0.835 \text{ m} \]

\( u^*/U_{ref} = 0.055 \)
Two-dimensional hill

- Two source positions: upwind face, downwind face.
- Operating conditions: $D = 100$ mm, $U_{ref} = 1$ ms$^{-1}$, $Q_{(CO2)} = 100$ litre.min$^{-1}$.
- Simultaneous LDA and FFID measurements (2 sources, 2 gases).

- Buoyancy effects in the dense gas plumes led to local flow deceleration near the upwind source and acceleration near the downwind source.
- Plumes showed significant upwind and greatly enhanced lateral spread (relative to the neutral density cases).
3. Two-dimensional back-step

Separating the hill at the crest gave a step aspect ratio, $W/h$, of 10, which was too small. Floor level downwind of the step was built-up to reduce the step height to 0.1m, increasing $W/h$ to 30 with $W/L_R \sim 5$.

Source centre 0.1m from the step. Floor downwind of the step either smooth or covered in the roughness elements. Run conditions, $D$, $U_{ref}$ and $Q$, as used with the hill model.

Dense gas plumes effectively two-dimensional.

Variants on the basic experiments saw arrays of cubical obstacles installed on the downstream surface.
4. Simple obstacle array, 0 and 45°

Simple Array, orientation 0°

Floor roughness to cease at source position
CO2, $x = 3.0\ m$, $z = 0.025\ m$, $U_{ref} = 1\ \text{ms}^{-1}$

Ran all simple and complex array cases at $Q = 50\ \text{l/min}$ to control plume width

$Q = 50\ \text{l/min}$

$Q = 100\ \text{l/min}$
5. Complex obstacle array
29 trees, 3 tree models plus 'no trees'
Trees ... ?

2 perpendicular discs, each 75 mm diameter, orientation 45°

wire mesh cylinder, treble thickness top section

porous wire wool sphere on narrow stem

Short names
disc

mesh

wool
Data for inverse modelling studies

- Four FFIDS operated simultaneously to generate long concentration time series.
- Experiments ran for 16 minutes, off-on-off, with 13 minutes of steady emission.
- Data for unobstructed flow, simple array, complex array; air and CO2.
- Both the raw data, sampled at 400 Hz, and equivalent full scale data made available.
- Geometrical scale of 1:200 assumed in converting the results to full scale, data first down-sampled to 100 Hz.
6. Urban area – central Paris
Sources S1, S2, S3 and associated wind directions.
Paris experiments

- Model comprised almost a hundred blocks.
- 1:350 scale implied that the ratio of full scale and model wind speeds was $\sqrt{350} = 18.7$.
- $1\text{ms}^{-1}$ wind tunnel reference speed equivalent to $18.7\text{ms}^{-1}$, or more usefully $9\text{ms}^{-1}$ at 10m height and $11.6\text{ms}^{-1}$ at the average building block height of 27m.
- Additional experiments were carried out with reduced emission rates and lower tunnel speeds to provide data for more realistic full scale conditions - dense gas effects were much reduced but not absent in these cases.
- Upwind spread ceased but vertical spread remained much reduced in all cases.
- Experiments were conducted with both continuous and short duration emissions.
Source 3; $U_{ref} = 1$ m/s, $Q_{CO2} = 50$ l/min

Upwind and lateral spread, $f(Ri, W_d/U)$
Paris and DAPPLE, C* decay correlation

Air emissions

Dimensionless concentration, C*

Source-receptor separation, R/H

DAPPLE correlation

- Source 1
- Source 2
- Source 3
- 50(R/H)^-2
- 10(R/H)^-1
Source S1, $U_{ref} = 0.8$ m/s  $Q = 35$ l/min, Air

Concentration

Emission, $T = 1, 2, 4, 8, 16, 32$ s ensembles of ~50 members
Source S1, $U_{ref} = 0.8 \text{ m/s}$, $Q = 35 \text{ l/min}, \text{CO}_2$

Concentration

Emission, $T = 1, 2, 4, 8, 16, 32 \text{ s}$ ensembles of \~50 members
### Data:

- \( C, c, U_i, u_i u_j, u_i c \)

with associated standard errors

3 minute averaging (Quality A),

1 minute averaging (Quality B).

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**Case** | Scale (m) | Ref Velocity (m/s) | Survey | Model | Instrument | X (m) | Y (m) | Z (m) | Raw Data Filename
--- | --- | --- | --- | --- | --- | --- | --- | --- | ---
None | 3 | 5 | <DATA_ROOT>| | |
None | 3 | 5 | <DATA_ROOT>| | |
None | 3 | 5 | <DATA_ROOT>| | |
None | 3 | 5 | <DATA_ROOT>| | |

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**Time (s)** | FF (C1) | FF (C2) | FF (C3) | FF (C4) | RV (V)
--- | --- | --- | --- | --- | ---
0.053 | 4 | 5.3 | 5.3 |
0.1945 | 3.8 | 4.3 | 4.3 |
0.3359 | 4.2 | 4.4 | 4.4 |
0.4773 | 4.5 | 4.6 | 4.6 |
0.6187 | 4 | 4.8 | 4.8 |
0.7601 | 3.8 | 4.5 | 4.5 |
0.9016 | 4.3 | 4.9 | 4.9 |
1.043 | 4.1 | 4.4 | 4.4 |
1.1844 | 4.1 | 4.7 | 4.7 |
1.3258 | 3.5 | 5 | 5 |
1.4672 | 4.1 | 5.4 | 5.4 |
1.6087 | 4.8 | 4.5 | 4.5 |
1.7501 | 4 | 4.9 | 4.9 |
1.8915 | 4.2 | 5.4 | 5.4 |
2.0329 | 3.7 | 5.1 | 5.1 |

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All data available as simple text or spreadsheet files with full metadata.

Release to third parties limited to collaborative use for the time being.

Full third party availability is intended – precisely when to be agreed.