A Simplified CFD Approach for Modeling Urban Dispersion

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Symposium on Planning, Nowcasting, and Forecasting in the Urban Zone
2004 AMS Annual Meeting
Seattle, WA
January 11-15, 2004
Objective and Approach

- To develop a fast, simplified CFD model suitable for emergency response applications
- Model targeted buildings explicitly with fine grid resolution and others as drag elements (or virtual buildings) with coarser grid resolution
- Some advantages
  - Greatly reduced computer time and storage
  - Less effort needed in grid generation
  - Ability to compute on much larger domains to provide improved parameterization, such as form drag, for use in larger scale models
Governing Equations

\[
\frac{\partial}{\partial \alpha} u_i + u_j \frac{\partial u_i}{\partial x_j} = - \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} (-u'_i u'_j) - C_d |u| u_i
\]

\[
\frac{\partial}{\partial x_j} u_j = 0
\]

\[
\frac{\partial C}{\partial \alpha} + u_j \frac{\partial C}{\partial x_j} = \frac{\partial}{\partial x_j} (-u'_j c')
\]

Plus appropriate turbulence model, such as Smagorinsky SGS turbulence model (1963) with wall damping function by Piomelli, et al. (1987)
Dispersive Simulation around a Cube: Solid vs. Virtual Building Approach

Atmospheric and Source Conditions:

Mean velocity: 0.6 m/s at $z = H$
Friction velocity: 0.0356 m/s
Neutral stability
Continuous source at 2H in front of the cube

Grid and Boundary Conditions:

Domain size (H): 8 x 6 x 2 (graded mesh)
No. of Grid points: 43 x 33 x 15 = 21,285
Boundary conditions:
   No slip on ground surface & no penetration on top boundary
   Logarithmic profile on the left inlet plane
Good agreement is seen regarding the main features of the flow field, including the stagnation zone, flow separations, and the large wake region. Pressure fields also compare reasonably well.
The virtual building approach reproduces essentially the same horseshoe-shape plume horizontally and very similar plume shape in the vertical except a small amount of tracer seeping through the virtual building near the ground surface.
Dispersion Simulations of a Hypothetical Tracer Gas Release in Downtown Salt Lake City

Atmospheric and Source Conditions:

- **Mean velocity**: 3 m/s at z = 10 m
- **Friction velocity**: 0.232 m/s
- **Source**: 1 kg/s (of tracer released on ground for 10 min)
- **Neutral stability**

Simulations: Solid Buildings | Virtual Buildings
---|---
**Domain size (m)**: 943 x 945 x 210 | 1000 x 1000 x 100
**Grid points**: 229 x 227 x 35 (~1.82 M) | 101 x 101 x 20 (~204K)
**Boundary conditions:**
- No slip on ground surface & no penetration on top boundary
- Logarithmic velocity profile on south inlet plan
Comparison of Velocity/Concentration Patterns from Two Different Treatments of Buildings

(a) Solid buildings

(b) Solid & virtual buildings

Non-targeted buildings are modeled as drag elements (or virtual buildings) without seriously compromising the overall solution accuracy.
Comparison of Velocity/Concentration Patterns from Solid and Virtual Building Approaches

Modeling the buildings as drag elements (or virtual buildings) leads to an order-of-magnitude savings in computer storage and cost.
Despite a slight under-prediction of certain peak values, the all virtual-building approach has yielded results similar to those from the more rigorous approach at significantly reduced cost.
Above data were used to construct steady and time-dependent boundary conditions, with logarithmic variations in the vertical direction, in the LES simulations.
Observed Data vs. Predicted Concentration Patterns (for t=50-55 min) Using Various BCs

LES Simulations of IOP7 Release 1
Winds: light and highly variable
Source: SF$_6$ released near ground at a rate of 1 g/s for 1 hour
Domain: 943 x 945 x 210 m (graded mesh)
Grid points: 229 x 227 x 35 (~1.82M)

(a) Steady BCs (averaged sonic 9 data)
(b) Time-dependent BCs (sonic 9 data)
(c) Time-dependent BCs (City Center data)
Comparison of Time-averaged Concentrations (for t=50-55 min) at SF$_6$ Sampler Locations

Instrumentation in the source vicinity of the Urban 2000 experiment in Salt Lake City. Yellow boxes indicate SF$_6$ sampler locations.

Comparison of predicted concentrations (with various boundary conditions) vs. observed data at SF$_6$ sampler locations for time = 50-55 min.
Conclusions

- A simplified CFD approach for modeling urban dispersion has been presented and early test results indicate the approach is highly cost-effective.

- Our simulation for a nighttime SF₆ release in the Salt Lake City downtown area demonstrates clearly the important role time-dependent forcing plays in such dispersion scenarios.

- For accurate dispersion predictions under light and variable winds, both temporal and spatial data to adequately describe the time-dependent forcing are needed.