Building Downwash – Problems, Solutions and Next Generation

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Why is this Important?
Its About Sustainability

**Sustainability**
We need an accurate dispersion model!

Social
Based on Needs

Economic
Non-Conservative Model

Environmental
Conservative Model

Bearable
Equitable
Viable
Economic
Non-Conservative Model

We need an accurate dispersion model!
Overview of Problems with Building Downwash

- Downwash theory based on research done before 2000
- Original theory based on a limited number of “solid” building shapes
- Schulman and Petersen documented problems for long and wide buildings and tall stacks at 10th modeling conference
- Theory is not suitable for porous, streamlined, wide or elongated structures
- CPP’s evaluation of theory has identified deficiencies and inaccuracies
- Recent and past model comparisons with observations
Examples Problems - Overprediction

From 10th Modeling Conference
Schulman, 2012, Wide/Long Building Issue

- Wide Buildings: Concentration increased by **factors of 3 to 14** when Width > 4 x Height

- Long Buildings: Concentration increased by **factors of 4 to 10** when Length > 4 x height for GEP stack.

- Field Observations at ALCOA TN wide/long facility: Model overpredicts by factor of ~10.
An Assessment of the AERMOD by IDEM
Keith Baugues, Assistant Commissioner

- Q:Q: Model Overpredicts by Factor of 2 or More
- Paired: Very Poor Agreement
AECOM Field Study at Mirant Power Station (Shea et al., 2012)

- Model overpredicted by factor of 10 on residential tower
- Better agreement with EBD, but still overpredicted by factor of 4
- Best agreement with no buildings, still overpredicted by factor of 2.
- In reality, plume is not affected by building downwash.

What’s Causing These Problems?
AERMOD Building Wake Problems – AERMOD Overestimates Downwash

- Wake height overestimated: need higher plumes to avoid downwash.

- Start of maximum building downwash farther downwind than in reality
Turbulence Calculations in Wake Flawed

- Constant downwash enhancement up to wake height (Fix?)
- Downwash enhancement decrease to ambient flawed (Fix?)

Starting Relation

\[
\frac{i_z}{i_o} = \left[ \frac{1 + \frac{\Delta \sigma_{wo}}{\sigma_{wo}} \left( \frac{\xi}{R} \right)^{\frac{2}{3}}}{1 + \Delta U_o/U_o \left( \frac{\xi}{R} \right)^{\frac{2}{3}}} \right]
\]

Where:

**Wake Velocity Deficit:**
\[
\Delta U_o/U_o = -0.7
\]

**Wake Turbulence Deficit:**
\[
\Delta \sigma_{wo}/\sigma_{wo} = 0.7
\]

- \(i_z\) = vertical turbulence intensity in wake
- \(i_o\) = upstream vertical turbulence intensity
- \(\xi\) = distance from lee edge of building

Height of Building Downwash Overestimated
(High Turbulence Zone >> AERMOD Overestimates)
More AERMOD Overestimates
Downwash (turbulence) enhanced by factor of ~10 under stable conditions: not documented (Fix?).

AERMOD Turbulence Enhancement Factor Starting at Lee Wall of Building

\[ i_z = i_{zo} \left[ 1 + \left( \frac{1.7 i_{zn}}{i_{zo}} - 1 \right) + \frac{\Delta U_o}{U_o} \right] \]

No Evidence Supporting This is Provided!!

Is PRIME really enhancing turbulence like this?
CPP’s Limited Research
Velocity Mapping for 1:1:2 Building
Findings from CPP’s Limited Research

- Wind tunnel measurements show little enhancement above building height (Fix?)

<table>
<thead>
<tr>
<th>Distance</th>
<th>Turbulence Increase Factor</th>
<th>AERMOD</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ξ/Hb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.7</td>
<td>1.0 to 5.7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4.4</td>
<td>1.0 to 5.2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.9</td>
<td>1.0 to 2.2</td>
<td></td>
</tr>
</tbody>
</table>
FDS LES Simulation for 1:1:2 Building

Very little downwash enhancement above the building
Other Problems
Streamline Calculation Comparison
Flawed (Bug?)

Given:
- \(H=W=L=R\)

PRIME Logic
- If \(L > 0.9R = 0.9L\) reattachment occurs, and \(H_r = H\)

For this case,
- \(L > 0.9R = 0.9L\), therefore \(H_r = H\)

That means all streamlines should be horizontal and they are not in example.

What is PRIME really doing?
Another Streamline Calculation Problem (Bug?)

Region B and C calculations should be equal at $x = 0$

They are a factor of two different.

$slope = \frac{dz}{dx} = 2 \left[ \frac{H_r - H}{R} \right]$ at $x = 0$, Region B

$slope = \frac{dz}{dx} = 4 \left[ \frac{H_r - H}{R} \right]$ at $x = 0$, Region C

\[
\frac{dz}{dx} = \frac{2(H_r - H)(x + R)}{R^2} \quad (-R \leq x < 0)
\]

\[
\frac{dz}{dx} = \frac{-4(H_r - H) \left( \frac{2x}{R} - 1 \right)}{R} \quad (0 \leq x < 0.5R)
\]
Streamlines for Lattice Structures Should be horizontal (Fix?)

- Refinery Structures Upwind
- Horizontal flow

- No Structures

- Solid BPIP Structure Upwind
Solutions and Next Generation (Sustainability)

• Short Term Fix: Use Equivalent Building Dimensions
  • EBDs are the dimensions (height, width, length and location) that are input into AERMOD in place of BPIP dimensions to more accurately predict building wake effects
  • Not a complete fix because of problems with the theory
  • Determined using wind tunnel modeling

• Next Generation: Improved AERMOD (and SCICHEM) and BPIP

• Collaboration between EPA and Industry
Short Term:
Advanced AERMOD Modeling to ~Fix
Typical AERMOD Overprediction Factors When Using BPIP Inputs and Current Theory

**FACTOR of 2 to 4**
reduction when EBD used

Hyperbolic cooling towers

**FACTOR of 4 to 8**
reduction when EBD used

Short building with a large foot print
Typical AERMOD Overprediction Factors When Using BPIP Inputs and Current Theory

**FACTOR of 2 to 3.5**
reduction when EBD used

Lattice Structures

**FACTOR of 2 to 5**
reduction when EBD used

Very Wide/Narrow Buildings
Why EBD helps but doesn’t solve problem

Why EBD Helps ~ reality

Very Long Building

Should not be enhanced here
Long Buildings with Wind at an Angle
Downwash Based on EBD and BPIP

Figures created in BREEZE® Downwash Analyst
BREEZE is a registered trademark of Trinity Consultants, Inc.
Typical AERMOD Underprediction Factors

- Factor of two: Corner Vortex
- Factor of 2-6: Upwind Terrain
The Next Generation Downwash Model
Moving Toward Sustainability

• Correct all the bugs
• Fix the known problems in the theory
• Incorporate the current state of science
• Advance the current state of the science
• Expand the types of structures that can be accurately handled
• Well documented and verified model formulation document and code for PRIME
• Add section to Appendix W that outlines a method to update model based on current research.
• Collaborate with industry to work toward an improved model
Thank You!

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