Wind Tunnel Modeling of Wind Affects on an Air Cooled Condenser

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Overview

I. Background Study

II. Physical Modeling Approach

III. Wind Tunnel Modeling

IV. Measurement Procedure

V. Future Plan
Research Targets

1. Building a physical (wind tunnel) model to simulate the wind effects on air cooled condensers.

2. Measuring re-entrainment and flow pattern changes for various wind conditions.

3. Look for approaches of mitigating adverse affects of wind
I. Background Study
General Info. about the Site

- **SITE**: El Dorado Power Plant, El Dorado, Nevada
- **PLANT OWNER**: Sempra Generation
- **LOCATION**: on 138-acres about 17 miles SW of Boulder & 40 miles SE of LV
- **PLANT TYPE**: Combined-cycle; fueled using natural gas
- **TOTAL GENERATING CAPACITY**: 480 MW
- **COMMERCIAL OPERATION DATE**: May 2000
ACC Facility at the Site

- ACC aligned to North - South
- The platform bottom is 63 ft tall
- A-frame is 28 ft n height
- 5 by 6 Fan array
  ( 5 lines w/ 6 fans on a line )
- Fan Diameter : 34 ft
- Volume : 1.3 M CFM ≈ 24 fps
  ( at full operation speed )
- 27.5 ft tall wind wall is installed
- Wind screens are installed
**Meteorology Data of the Site**

Windrose for El Dorado Site

**Period:** Aug. 01 through Oct. 04  
**Sampling Frequency:** 1 / hour  
**Sampling Count:** 19,005 samples  
**Average Speed:** 7.7 MPH  
**Dominant Direction**
- SSW : 18.1 %  
- S : 15.0%  
- SW : 12.6 %  
- WSW : 8.3 %  
- SSE : 8.1 %

* 17 MPH and above  
* 10 - 17 MPH (7.6m/s)  
* 6.0 - 10 MPH (4.5m/s)  
* 3.5 - 6.0 MPH (2.7 m/s)  
* 0.5 - 3.5 MPH (1.6 m/s)

* Calm wind (below 0.5MPH) : 0.7 %
II. Physical Modeling Approach
Equations of Wind Flow

Continuity
\[ \frac{\partial \overline{U}_i}{\partial t_i} = 0 \quad \text{and} \quad \frac{\partial \rho}{\partial t} + \frac{\partial (\rho \overline{U}_i)}{\partial x_i} = 0 \]

Momentum
\[ \frac{\partial \overline{U}_i}{\partial t} + \overline{U}_j \frac{\partial \overline{U}_i}{\partial x_j} + 2 \varepsilon_{ijk} \Omega_j \overline{U}_k = -\frac{1}{\rho_0} \frac{\partial \overline{P}}{\partial x_i} - \frac{\overline{\delta T}}{T_0} g \delta_{i3} + \nu_0 \frac{\partial^2 \overline{U}_i}{\partial x_j^2} + \frac{\partial (\overline{-u_j u_i})}{\partial x_j} \]

Energy
\[ \frac{\partial \overline{\delta T}}{\partial t} + \overline{U}_i \frac{\partial \overline{\delta T}}{\partial x_i} = \left[ \frac{\kappa_0}{\rho_0 c_{p_0}} \right] \frac{\partial^2 \overline{\delta T}}{\partial x_k \partial x_k} + \frac{\partial (\overline{-\theta u_i})}{\partial x_i} + \frac{\phi}{\rho_0 c_{p_0}} \]
Non-Dimensional Parameters

Non-dimensionalizing these equations gives five similarity parameters:

- **Rossby Number:**
  \[ R_0 \equiv \frac{U_0}{L_0 \Omega_0} \]

- **Densimetric Froude Number:**
  \[ Fr \equiv \frac{U_0}{\left( gL_0 \delta T_0 / T_0 \right)^{1/2}} \]

- **Prandtl Number:**
  \[ Pr \equiv \frac{\rho_0 c_{p_0} \nu_0}{\kappa_0} \]

- **Eckert Number:**
  \[ Ec \equiv \frac{U_0^2}{c_{p_0} \delta T_0} \]

- **Reynolds Number:**
  \[ Re \equiv \frac{U_0 L_0}{\nu_0} \]
## WT Modeling Criteria

<table>
<thead>
<tr>
<th><strong>Ro</strong> $\equiv \frac{U}{L\Omega}$</th>
<th>Assume short length scales $\rightarrow$ negligible Coriolis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can neglect $Ro$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Fr</strong> $\equiv \frac{U}{gL \frac{\delta T}{T}}$</th>
<th>Assume neutral atmosphere (constant density)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can neglect $Fr$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Pr</strong> $\equiv \frac{\rho c_p \nu}{\kappa}$</th>
<th>Testing using air (same fluid as atmosphere)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pr same in tunnel and atmosphere</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Ec</strong> $\equiv \frac{U^2}{c_p \delta T}$</th>
<th>Assume incompressible flow (Boussinesq approximation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can neglect $Ec$</td>
<td></td>
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</tbody>
</table>
Important Criteria for WT Model

- Power-law velocity-profile equation:
  \[ \frac{U}{U_\infty} = \left( \frac{z}{\delta} \right)^\alpha \]

- Reynolds number independence:
  \[ \text{Re}_z = \frac{u_*z_o}{\nu} \geq 2.5 \]
  or \[ \text{Re} = \frac{u \cdot L}{\nu} \geq 15,000 \] by Ricou & Spaulding
III. Wind Tunnel Modeling
# Parameters & WT Model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>At the site</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed</td>
<td>Varies by nature</td>
<td>4 typical speeds</td>
</tr>
<tr>
<td>Wind Direction</td>
<td>Varies by nature</td>
<td>5 major direction</td>
</tr>
<tr>
<td>Each Fan Volume</td>
<td>1.3 M CFM</td>
<td>Scaled down</td>
</tr>
<tr>
<td>ACC Height</td>
<td>63 Ft</td>
<td>Scaled down</td>
</tr>
<tr>
<td>Wind Wall Height</td>
<td>27.5 ft</td>
<td>Scaled down</td>
</tr>
<tr>
<td>Wind Screen Set</td>
<td>60-99% porous</td>
<td>Same as the site</td>
</tr>
<tr>
<td>Adjacent Building or any structure</td>
<td>Fixed</td>
<td>Scaled down</td>
</tr>
</tbody>
</table>
Modeling Scale

- Isyumov criteria
  : Flow distortion due to the tunnel blockage can be negligible at 5% or less blockage ratio
- Cross sectional area of UCD ABLWT: 1.2 mX1.6 m=1.92 m²
- Model dimension needs to be less than
  : 1.2X1.6X5%=0.096 m² to meet Isyumov criteria
- Size of ACC facility at the site: 233’X28’ = 6,524 ft² ≈ 606 m²
- Modeling scale needs to be larger than 79
- Modeling scale of 1 : 260 (cause 0.5% block) was chosen
  : for the consideration of fan availability and ABL thickness
    (typical ABL thickness
      366m for suburb, 274m for open terrain, 213 for ocean)
WT Modeling Procedure (1)

- WT model was set on a turn table (Ø1.1m) for easy changing of wind direction.

: most structures are built on the table
WT Modeling Procedure (2)

- The turn table was centered at 2\textsuperscript{nd} fan row to avoid any interference of the WT wall
WT Modeling Procedure (3)

- ACC height and wind screen were installed to be easily adjustable and matching porosity patterns.
WT Modeling Procedure (4)

- PC cooling fans with 4 X 4 X 1 cm dimension were used to simulate the ACC fans.
WT Modeling Procedure (5)

- All of tubes and wires were mostly hidden
WT Modeling Procedure (6)

- An electric power controller for the speed variation of the micro fans was built: each fan consumes 1 W (12 V & 80 mA) power
Final Shapes of the Model
Verification of Model Geometry
Visualization of Air Entrainment
IV. Measurement Procedure
**Typical Characteristics of B.L.**

For desert terrain

\[
\frac{1}{n} \approx 0.1 - 0.15
\]

For UCD ABLWT test

\[
\frac{1}{n} \text{ is set to } 0.13
\]
Importance of using ABLWT
UC Davis ABLWT (1)
UC Davis ABLWT (2)

Power Spectral Density Distribution
(for alpha in power-law 0.31 at 11 inch height)

- UCD ABLWT
- -5/3 Law

UC Davis
Atmospheric Boundary Layer Wind Tunnel
Testing Apparatus

- Probe
- Exhausted Gas
- Re-entrainment
- Transducers
- Ethane Gas

For flow measurement:
- Hot wire and CTA

For concentration measurement:
- Hydrocarbon gas analyzer
Concentration Level Distribution

![Graph showing concentration level distribution against height (mm) and concentration level (PPM). The graph includes a scale of 63 ft (real scale).]
Re-entrainment Ratio Calculation

- Re-entrainment ratio, \( R \)

\[
R = \frac{\dot{m}_i}{\dot{m}_e}
\]

\[
\dot{m}_e = \rho_{\text{ethane}} \times \dot{Q}_e
\]

\[
\dot{m}_i = \int \rho_{\text{ethane}} \cdot C(z) \cdot u(z) \, dA
\]
Exhausting Flow Speed

Flow distribution measured at 1-D above the steam header

Distance from one edge of ACC [mm]

Speed [m/s]
V. Future Plans
Future Plan

Current Testing Scope
- Flow visualization of strong re-entrainment
- Flow pattern measurement
- Re-entrainment measurement

Next Step
- Validation of mitigation proposal
- Application of the WT model with different parameters