Physically-based numerical framework for wind turbine noise prediction

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openWind, created by AWS Truewind, is an open-source wind farm design software

[http://www.awsopenwind.org/]
Weibull Distribution

$P \propto U^3$

$\delta U = U_0 \left( 1 - \sqrt{1 - C_t} \right) \left( \frac{D_0}{D_0 + 2kX_{01}} \right)^2 \frac{A_{\text{overlap}}}{A_1}$

$U_1 = U_0 - \delta U < U_0$

Can we do better?
Mesoscale modelling

• A mesoscale model is a **numerical weather prediction (NWP)** model with sufficiently high horizontal (≈30 km) and vertical resolution to forecast mesoscale weather phenomena in coastal and mountainous regions.

**Sea breeze**
Canadian Numerical Wind Atlas

Mean Wind Speed at 50 m above ground, 5 km resolution

by Wei Yu, email: Wei.Yu@ec.gc.ca
Wind Energy Simulation Toolkit (WEST)

Global Climate Database (Shown North America)
Resolution: 200-500 km

Mesoscale simulations

Mesoscale wind climate database
Resolution: 1-5 km

Microscale simulations

Microscale wind statistics
Resolution: ~50m

Geophysical database
MS-micro

• Based on the theory of Jackson & Hunt (1975)
• A neutrally stratified flow is assumed
• Simple mixing-length turbulence model
• Does not resolve circulation
• Ability in complex terrain?
Mesoscale model

Component 2
urbanGEM/LAM

Component 3
2-way interaction?

Component 1
urbanSTREAM

Component 4
urbanLS
urbanEU

Component 5 (whole system validation)

Adaptive sampling strategy
Bayesian inference for inverse source determination
urbanBLS
urbanAEU

 CRTI

$U_i, u_i u_j, u_i u_j, \bar{e}$
CFD software

**ANSYS FLUENT** is a *commercial* flow modeling software

http://www.ansys.com/products/fluid-dynamics/fluent/

**urbanSTREAM** is an *in-house* CFD code developed at U of Waterloo (CANADA)

Internal combustion engine and the flow inside modeled using ANSYS FLUENT software
Support for 2010 Winter Olympics in Vancouver City

- 16 CPUs on saw.sharcnet.ca
- $380 \times 380 \times 70 = 10.108 \text{ million nodes}$
BC Place Stadium
Reason to develop a multiscale (meso-micro) system for wind power prediction

- If wind speed increases from 7 m/s to 7.5 m/s, it would yield 13% of gross profit per turbine

Accuracy of wind speed at hub height of a wind turbine is important!

**Micrositing:** to locate wind turbines in a wind farm to maximize annual energy production using CFD
Acoustic imaging measurements are limited to frequencies above 100Hz.

Blade to tower interactions are briefly noticed.

Andy Metelka, Sound & Vibration Solutions (SVS) Canada Inc.
Flow over a single cylinder

• Computational domain:

- Computational domain:
  - D=0.019m  Re=90,000
  - Inlet Mach=0.2
  - 15°C air: ρ=1.225kg/m³
  - μ=1.7894E-05 kg/m/s
  - Δt=3.17E-07 s
  - 200,000 Δt before recording

by Ping Ma

University of Waterloo

Freestanding taper tower
Receiver located at 90 degree from the free stream direction, **128 D away from the cylinder**
Flow chart

Fluent (static pressure on cylinder surface) → 3D acoustic code (sound pressure fluctuation at receiver’s location) → Matlab FFT (SPL vs. St)

Farassat 1 formulation

\[ 4\pi p'(x, t) = 4\pi p'_T(x, t) + 4\pi p'_L(x, t) \]

\[ = \frac{\partial}{\partial t} \left\{ \int_{f=0} \left[ \frac{\rho_0 v_n}{r(1-M_r)} + \frac{p \cos \theta}{c r(1-M_r)} \right] dS + \int_{f=0} \left[ \frac{p \cos \theta}{r^2 (1-M_r)} \right] dS \right\} \]

LES or URANS

retarded time at t-r/c
Single-rotor

Koda, 2011

Isosurface plot of Z vorticity at 70[s⁻¹]
Counter-rotating wind turbine

http://www.ahaenergy.com/
Dual-rotor

Isosurface plot of Z vorticity at 120[s⁻¹]
What next?

Acoustic imaging measurements are limited to frequencies above 100Hz.

Blade to tower interactions are briefly noticed.

Blade/tower interactions & noise prediction