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Vertical Axis Wind Turbine Noise

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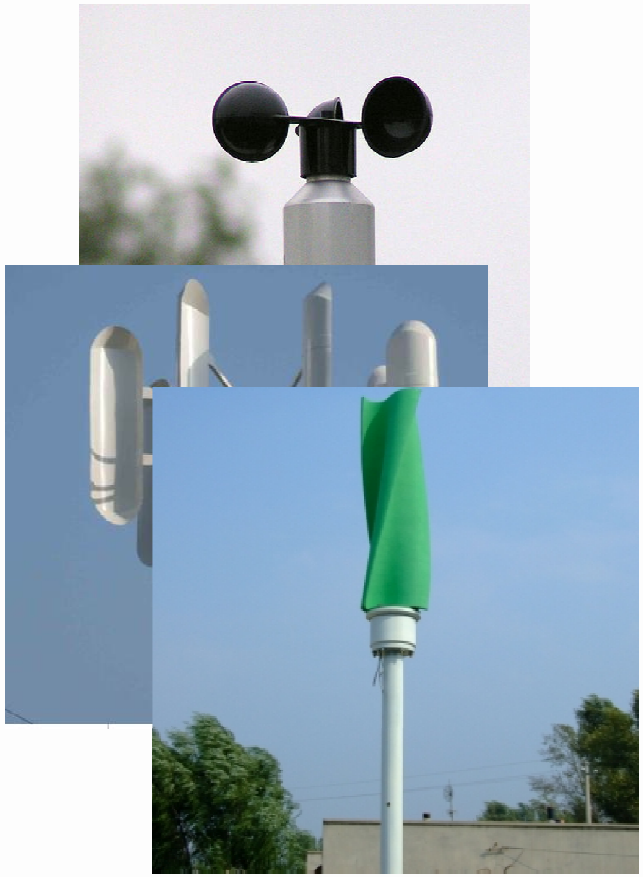
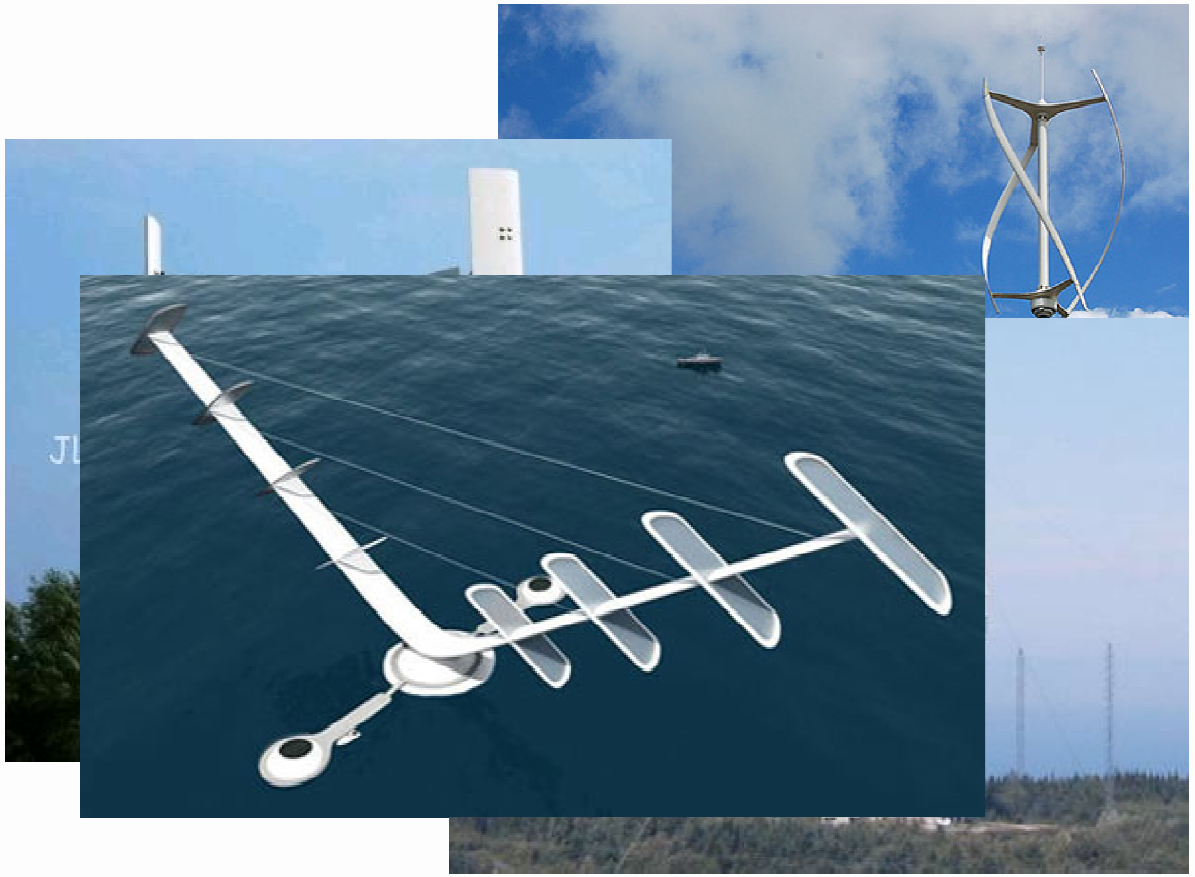
What is a VAWT?

Drag Type



Lift Type



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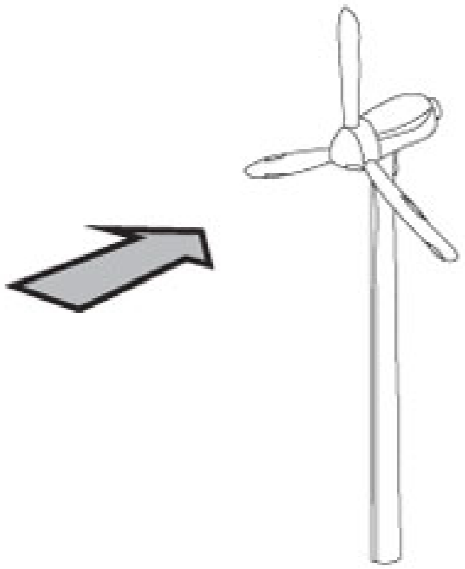
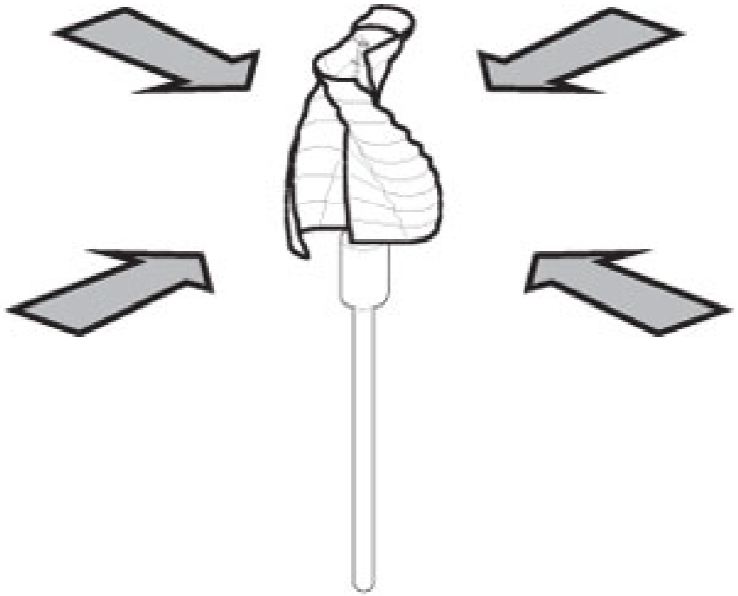
Why VAWTs?



Horizontal Turbine

Must have smooth laminar wind flow from a single direction.



Vertical Turbine

- Functions in wind from any direction.
- Functions in Turbulent or gusty winds.

Ideal for built environment…

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Built Environment Application

Issues:

- Turbines are in close proximity to people.
- Noise is a potentially significant problem

Objectives:

- Identify dominant mechanisms of noise generation.
- Investigate possible methods for reducing radiated sound.

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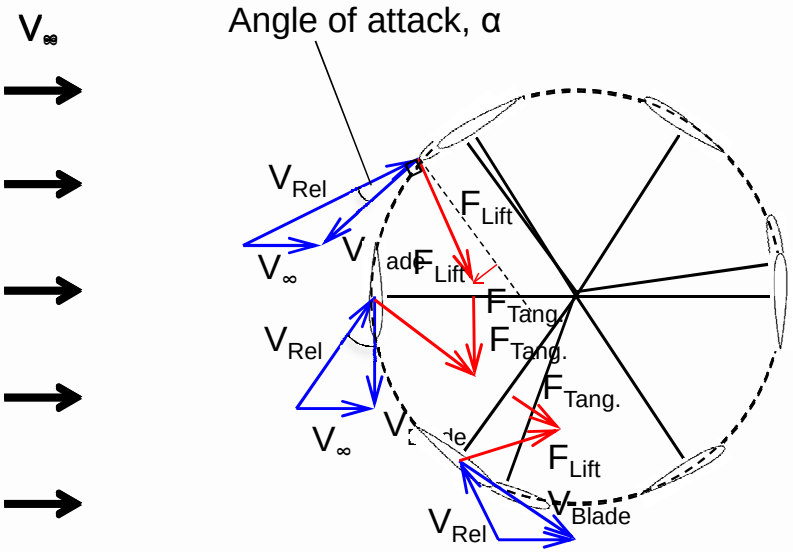
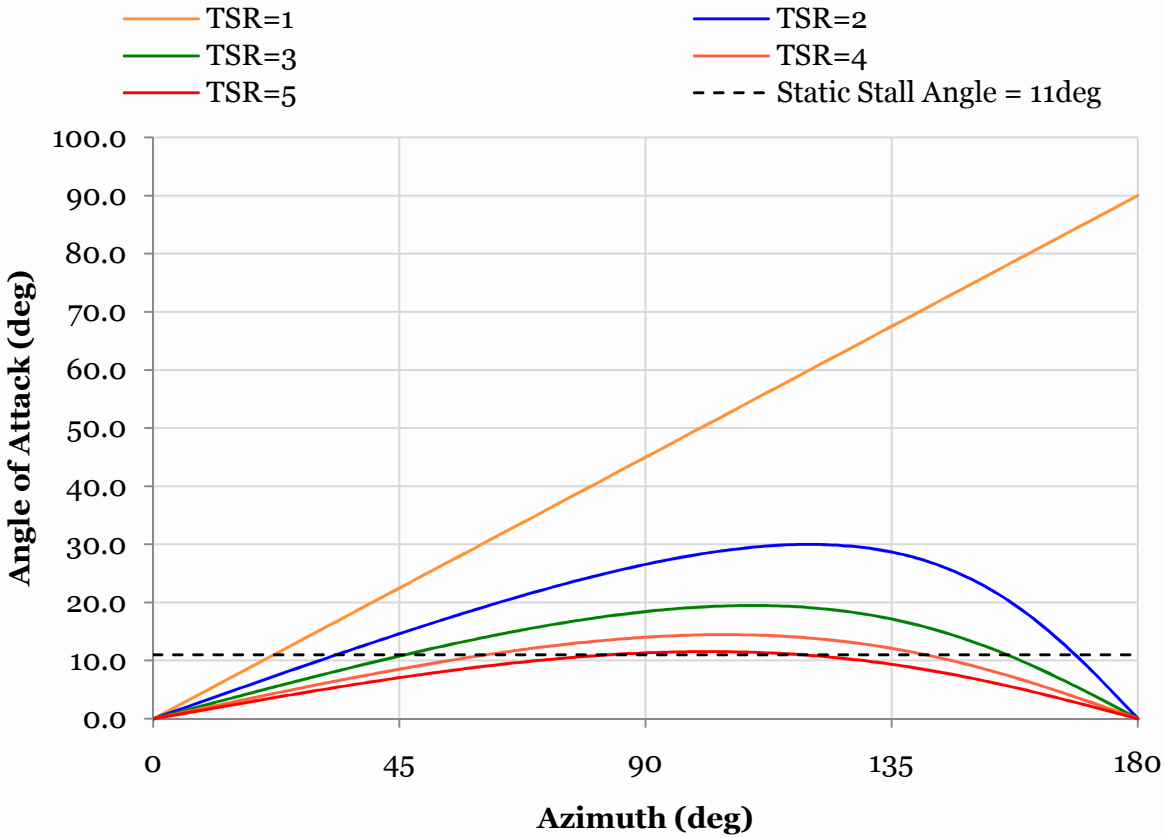
How does a lift-type VAWT work?





Key Parameter: Tip Speed Ratio

TSR= Blade speed / Wind Speed

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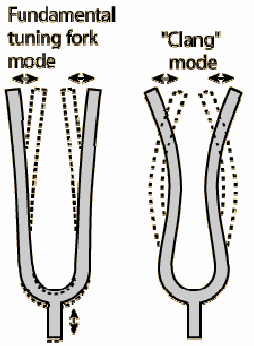
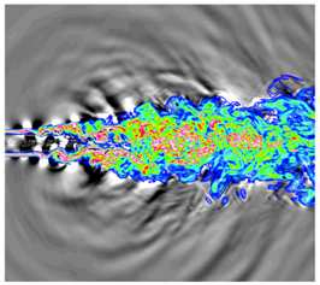
Where does noise come from?

Kinetic energy is converted into acoustic energy by three mechanisms:

1. By forcing the mass in a fixed region of space to fluctuate, e.g. a loudspeaker in a large baffle.
2. By forcing the momentum in a fixed region of space to fluctuate, e.g. a solid object vibrating after being struck.
3. By forcing the rates of momentum flux across fixed surfaces to vary, e.g. turbulent jet.





Definitions from MJ Lighthill, 1952, *On Sound Generated Aerodynamically*, Proc. R. Soc. Lond. A, Vol.267, 147-182
Jet noise image from: http://cms.tacc.utexas.edu/news/feature-stories/2011/reducing-jet-noise-by-controlling-turbulence/

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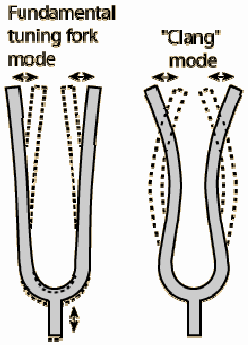
Where does VAWT noise come from?



- Dipole noise due to fluctuating blade loads dominates at low Mach number.
- Need to know the blade loads in order to determine the noise analytically.

- This presents some significant problems…

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CFD Modeling?

- Flow is fundamentally unsteady
- Flow is 3D
- Flow is turbulent and has a wide range of length and time scales

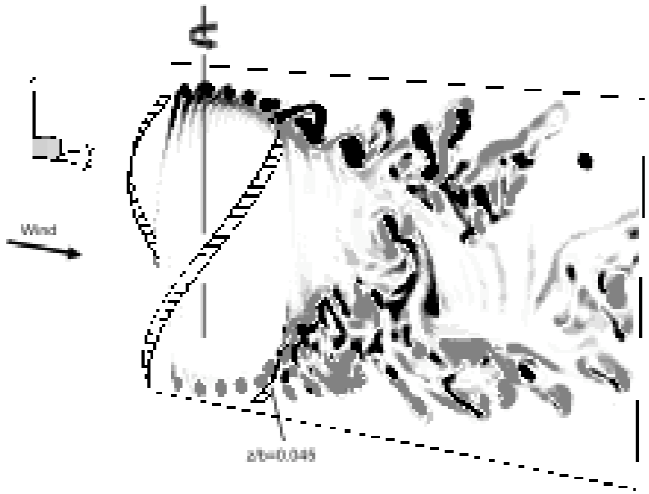

Image from Scheurich, Fletcher and Brown, (2010), *The influence of Blade Curvature and Helical Blade Twist on the Performance of a Vertical Axis Wind Turbine,* 48th AIAA Aerospace Sciences Meeting, Orlando, USA

Flow is VERY complicated!

Difficult to determine the most

An alternative approach…

1. Use analytic acoustic model for moving point source.
2. Guess the blade loads
   - Sinusoidal variation with azimuth?
   - Blade/wake interactions?
   - Dynamic Stall?
3. Predict the resulting sound field
4. Identify key characteristics of sound field for comparison with experimental data.

Far field:

$$\rho - \rho_0 = \left[\frac{x_i - y_i}{4\pi a_0^2 r^2 (1 - M_r)^2}\left\{\frac{\partial F_i}{\partial t} + \frac{F_i}{1 - M_r}\frac{\partial M_r}{\partial t}\right\}\right]$$

Near field:

$$\rho - \rho_0 = \left[\frac{1}{4\pi a_0^2 r^2 (1 - M_r)^2}\left\{\frac{F_i (x_i - y_i)}{r}\frac{(1 - M^2)}{(1 - M_r)} - F_i M_i\right\}\right]$$

MV Lowson, (1965), *The Sound Field for Singularities in Motion,* Proc. R. Soc. A, Vol.286, 559-572

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Loading Profiles Tested

Define normal and tangential blade loads as a function of azimuth:

Constant Load

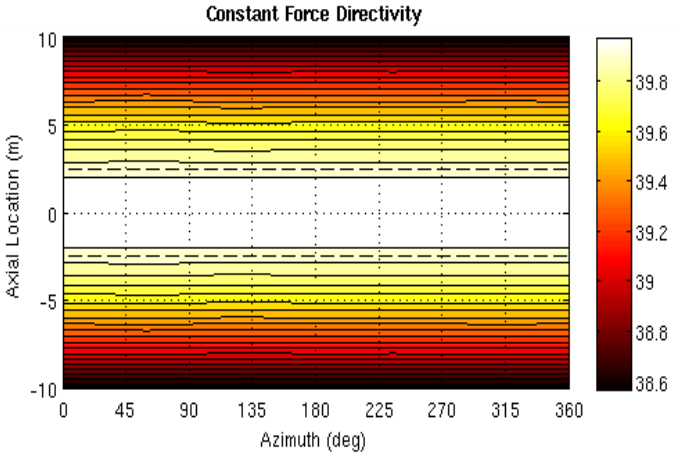
- Zero wind load
- Constant drag load

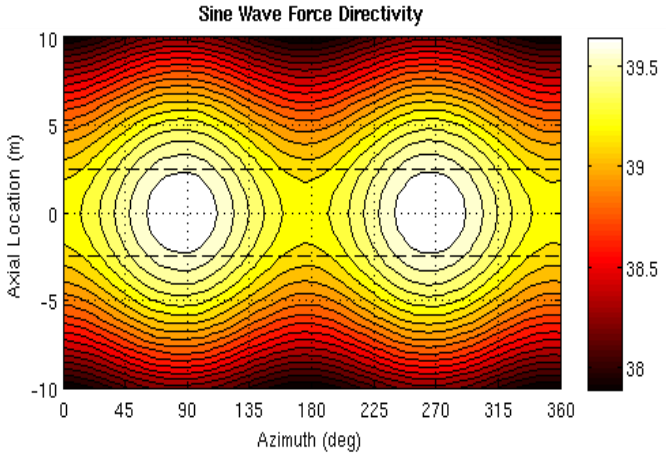
Sine Wave

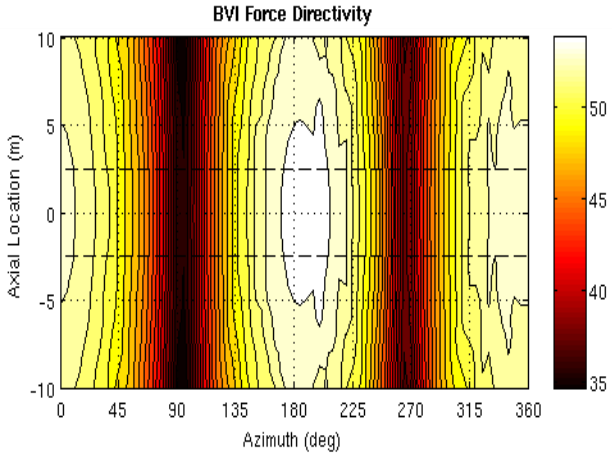
- Loads you would get if there were no blade/wake effects.

Blade Vortex Interaction

- Load due to the blade passing close to a coherent vortex.







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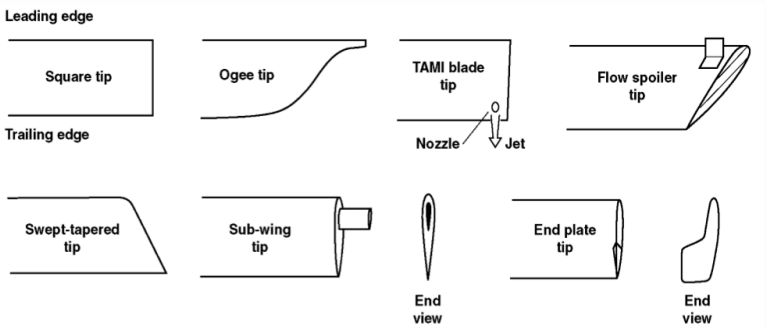
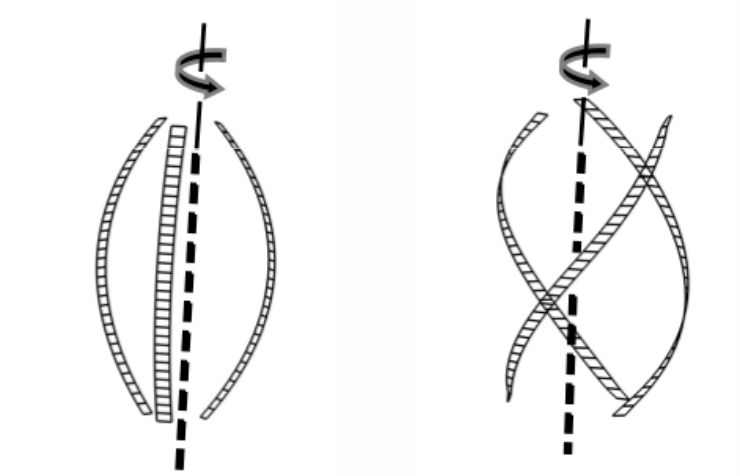
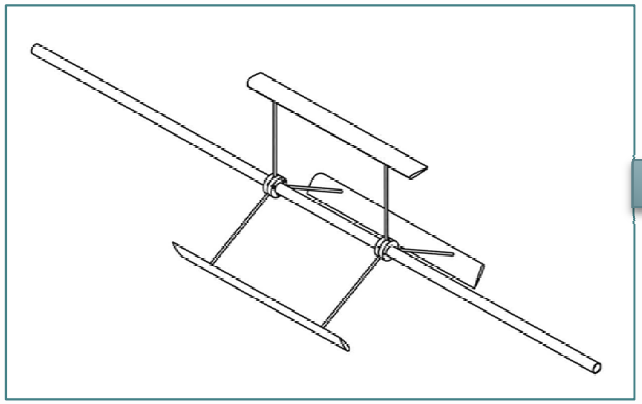
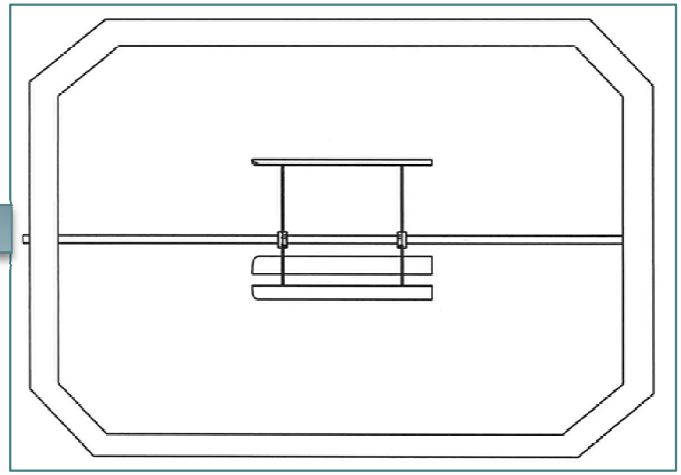
Experiments

- Use acoustic array in Markham wind tunnel to locate dominant noise sources.
- Investigate parameters for noise reduction
  - Blade tip shape
  - Spoke geometry
  - Variable radius
  - Blade sweep / helical blades









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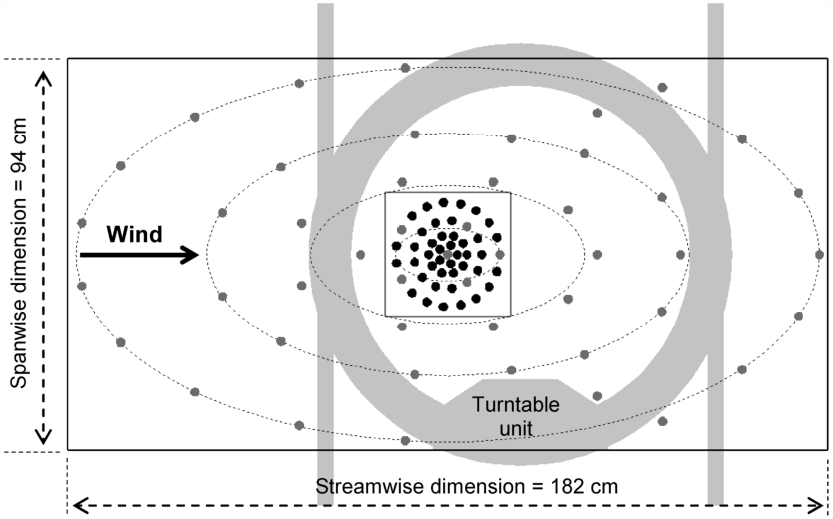
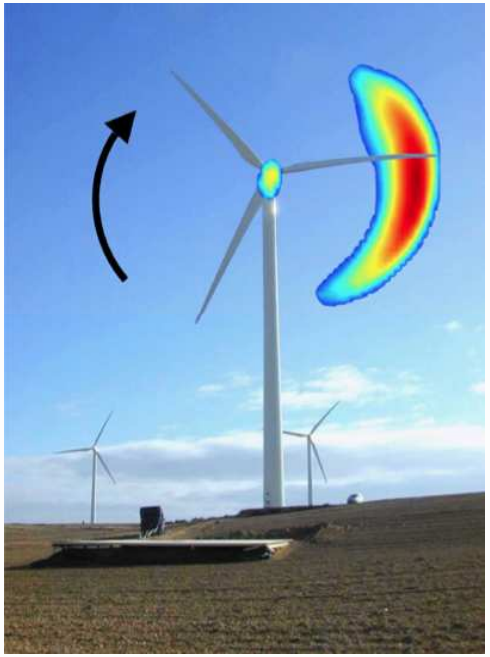
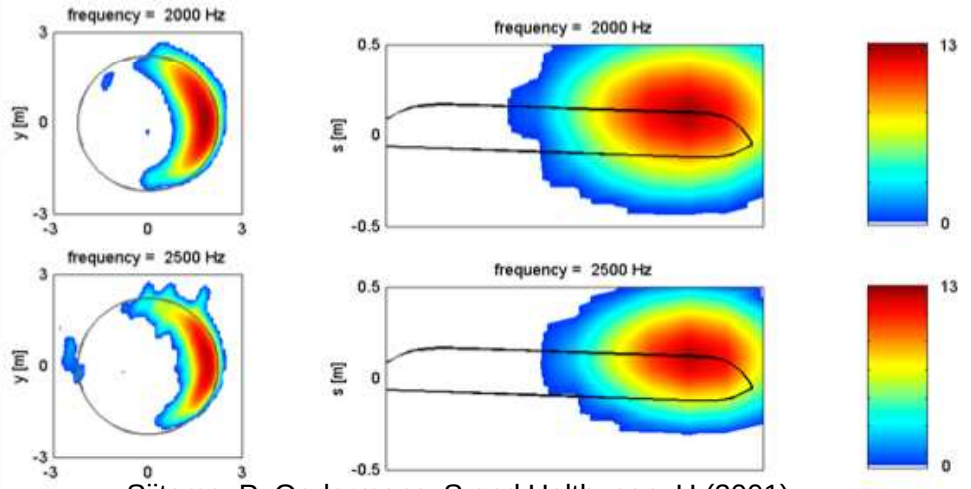
Array Measurements





Sijtsma, P (2004), *Experimental techniques for identification and characterisation of noise sources,* National Aerospace Laboratory NLR Report, NLR-

- Use phase relationship between signal received at multiple microphones.



Sijtsma, P, Oerlermans, S and Holthusen, H (2001), *Location of Rotating Sources by Phased Array Measurements,* NLR-TP-2001-135

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Plan of action

- Measure sound field in the wind tunnel using acoustic array.
- Compare results with computer model predictions.
- Investigate dominant noise sources in detail.

- Inform the design of quieter VAWTs

Questions?