Aerodynamic Damping

in the Design of Support Structures for Offshore Wind Turbines

David Cerda Salzmann
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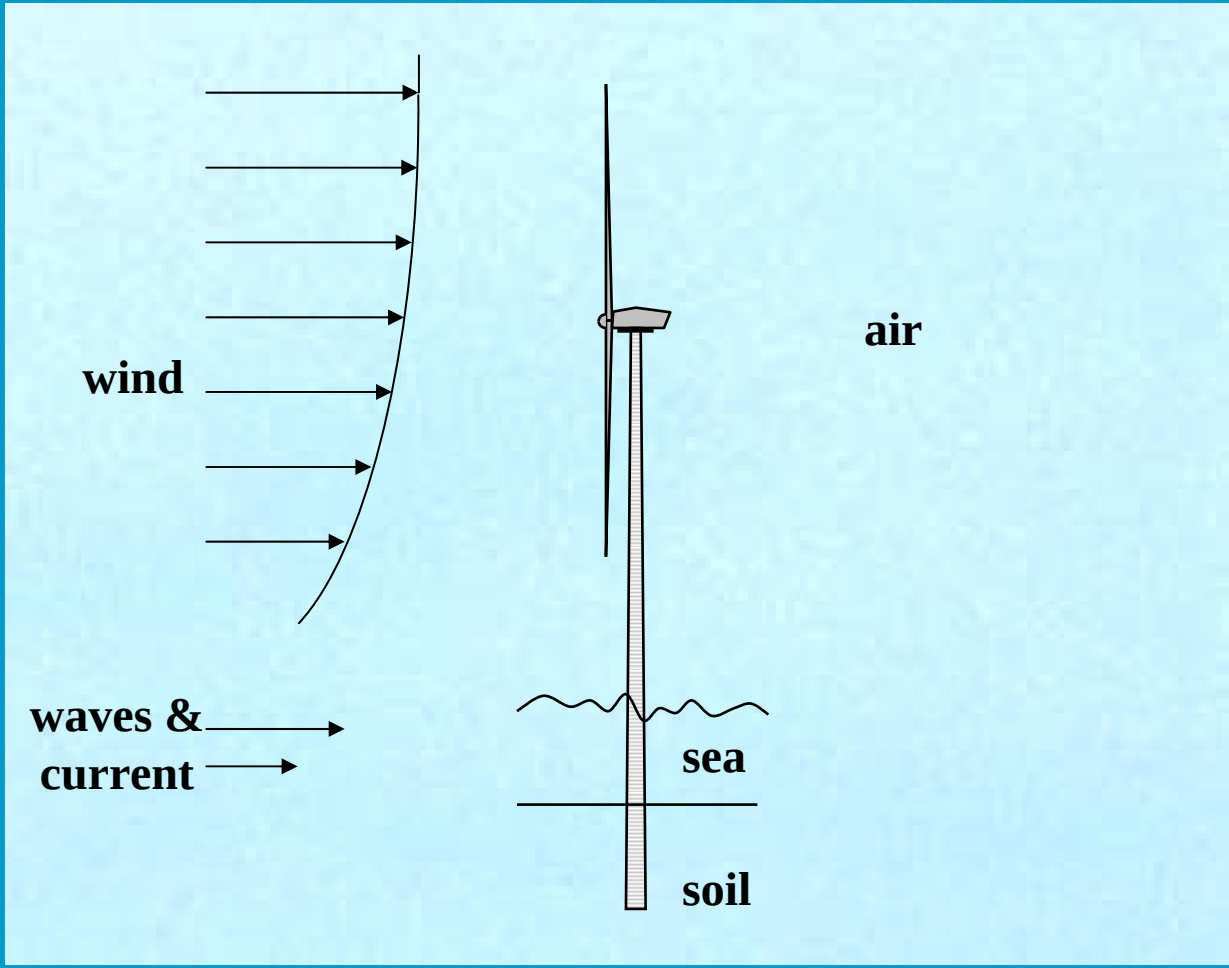
Aerodynamic Damping



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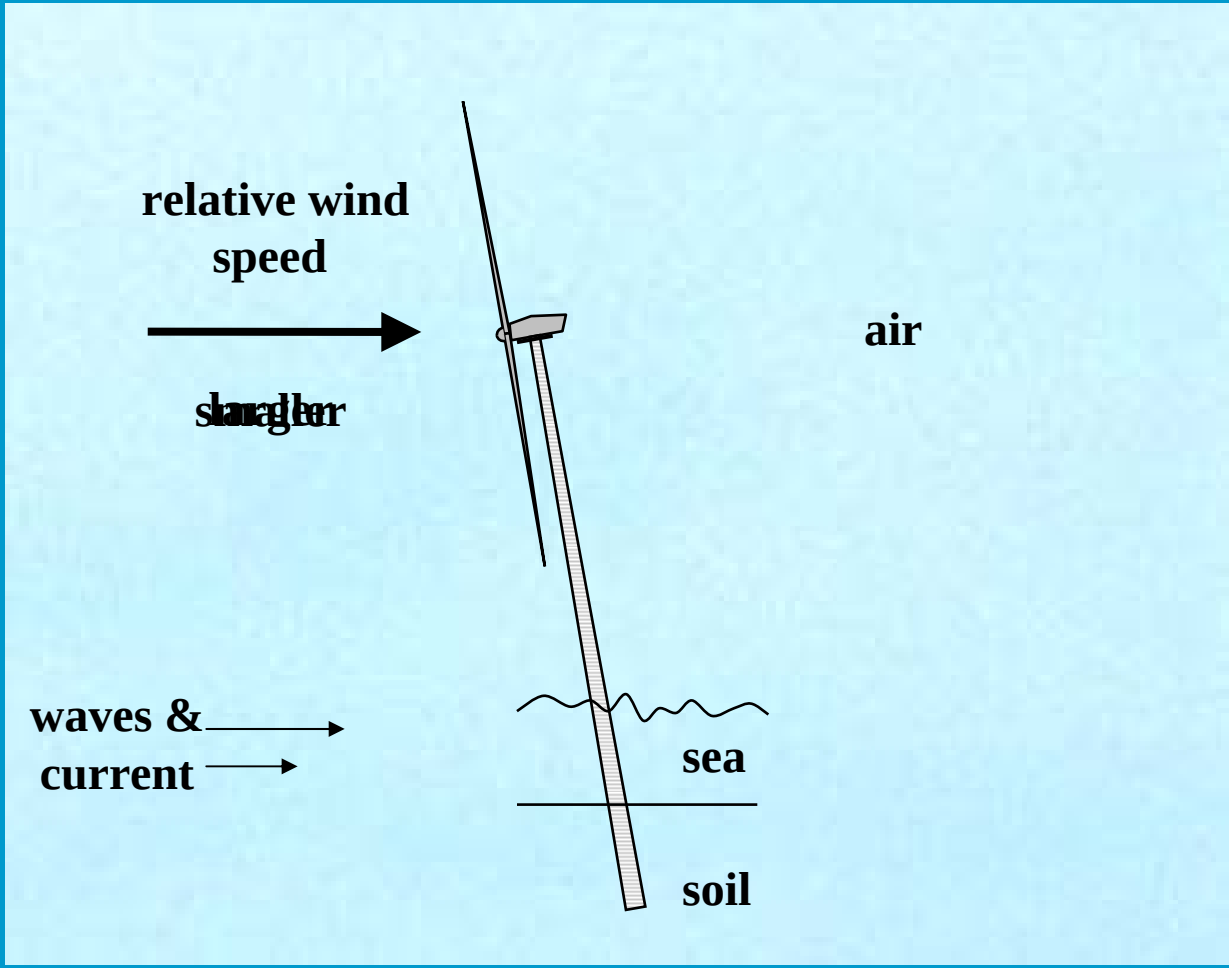
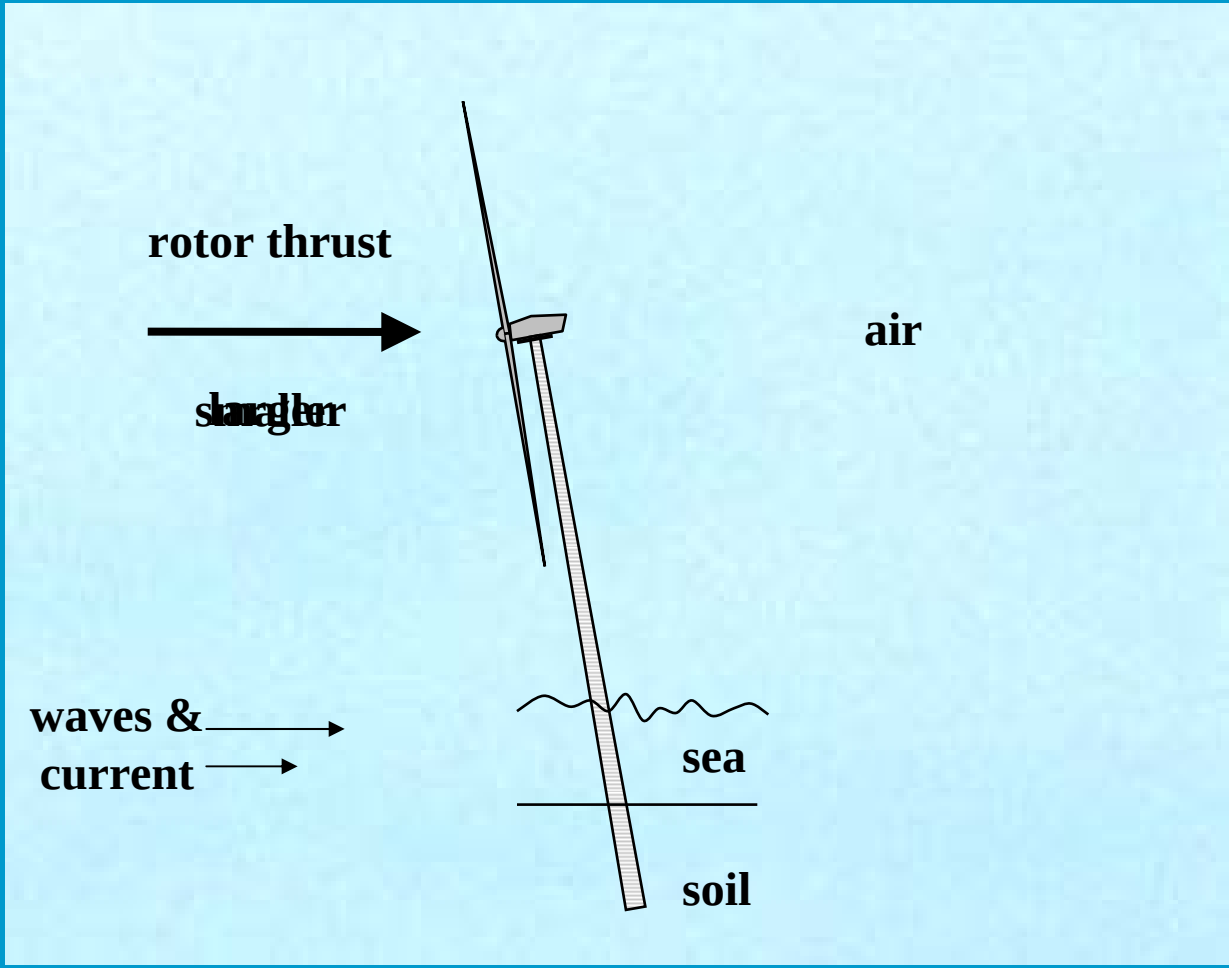
Aerodynamic Damping



Aerodynamic Damping



Aerodynamic Damping

- Fore-aft motion
- Change in relative wind speed
- Change in rotor thrust
- Aerodynamic damping

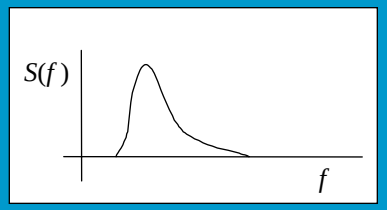
- Significant effect on lifetime!

Aerodynamic Damping

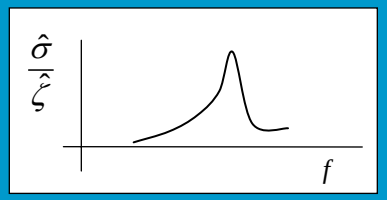
- Time domain simulations: effect included
- Frequency domain calculations: effect must be added

Frequency Domain Calculations

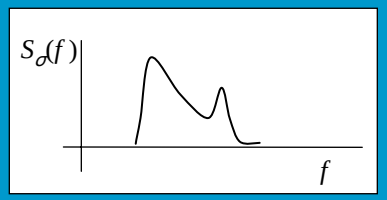
wave spectrum



transfer function



response spectrum



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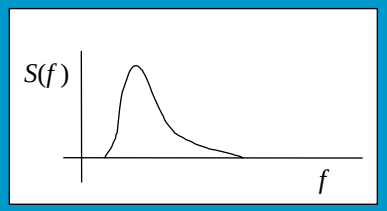
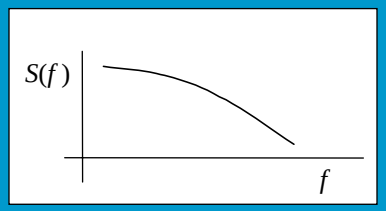
Frequency Domain Calculations

wave spectrum



wind spectrum



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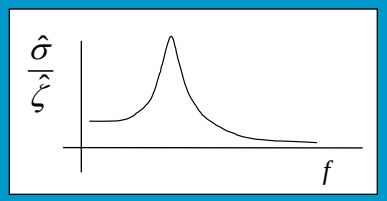
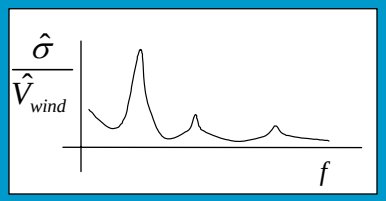
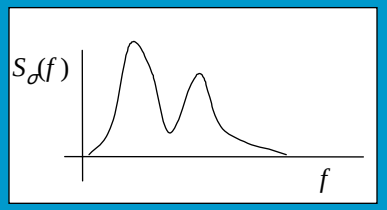


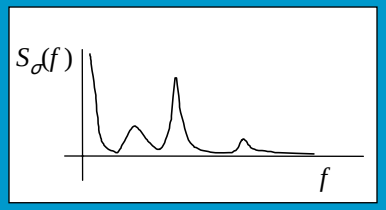
transfer function



response spectrum waves



response spectrum wind



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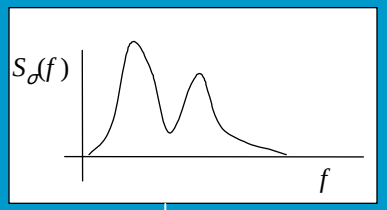
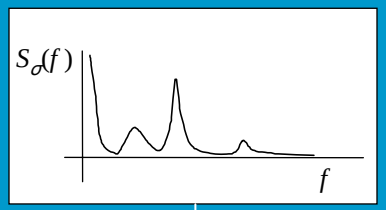
Frequency Domain Calculations

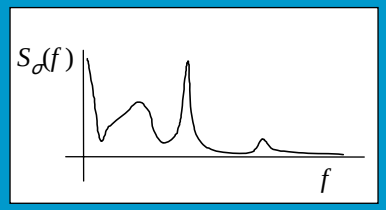
response spectrum waves





response spectrum wind

Aerodynamic damping



response spectrum

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Literature

Extensive work on aerodynamic damping done by

- Andrew Garrad
- Martin Kühn
- Jan van der Tempel

For constant rotor speed turbines

Constant speed turbines Garrad

Assumptions:

- small angles of inflow
- high tip speed ratio
- unstalled

Result:

- Damping per blade element:

$$\xi_{aero} = \frac{c_{damping}}{c_{cr}} = \frac{\rho V_{rot}\, c\, C_{L_\alpha}}{4\, m\, \omega_n}$$

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Constant speed turbines
Kühn

- Closed-form
- Free vibration
- Numerical linearization

$$\xi_{aero} = \frac{N_b \rho \Omega}{4 M_0 \omega_n} \cdot \int_{R_{root}}^{R} C_{L_\alpha L} c(r) r \, dr$$

- Simplified closed-form

$$\xi_{aero} = \Omega \cdot \frac{N_b \rho C_{L_\alpha} m_{1b}}{4 M_0 \omega_n}$$

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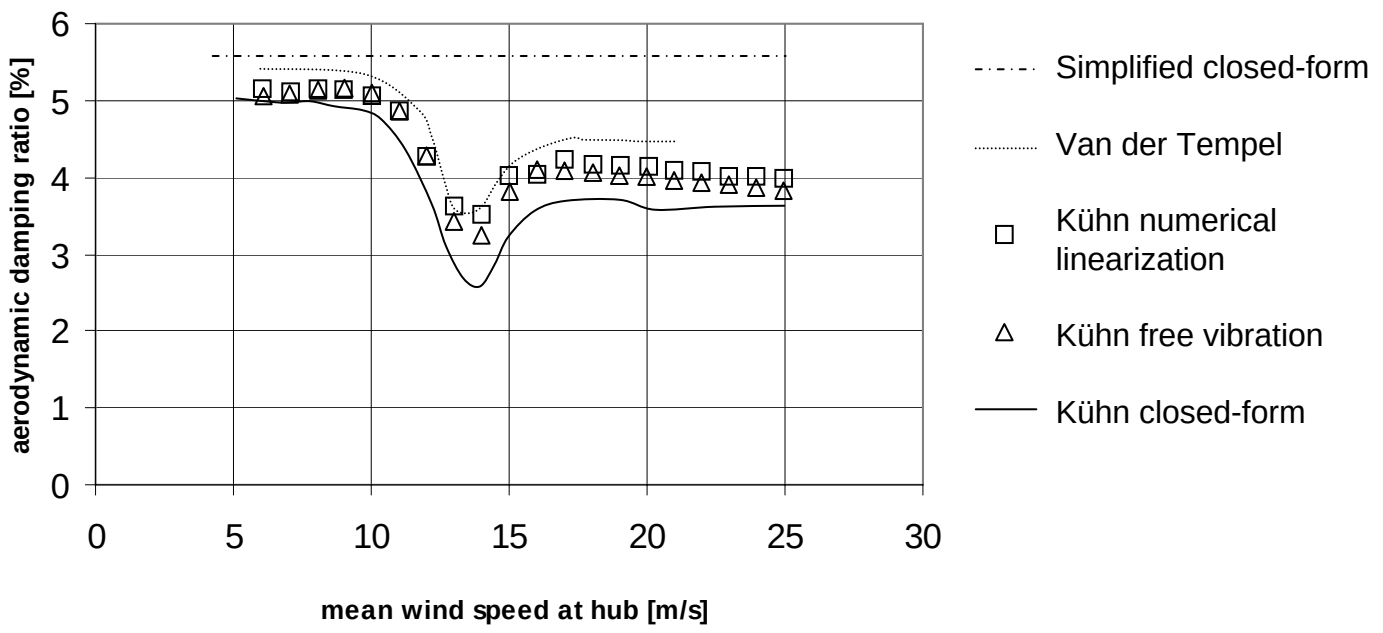
Constant speed turbines
Van der Tempel

- Changes in rotor thrust

$$\xi_{aero} = \frac{T'}{dV_d} \cdot \frac{1}{2 M_0 \omega_n}$$

Constant speed turbine Opti-OWECS



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Variable speed turbines damping per blade element

Differences compared to constant speed:

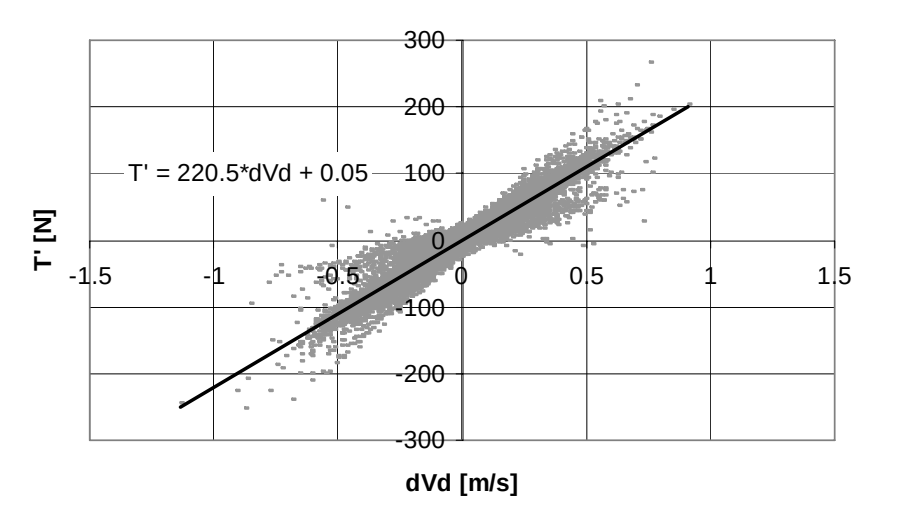
- Tip speed ratios
- Angels of inflow

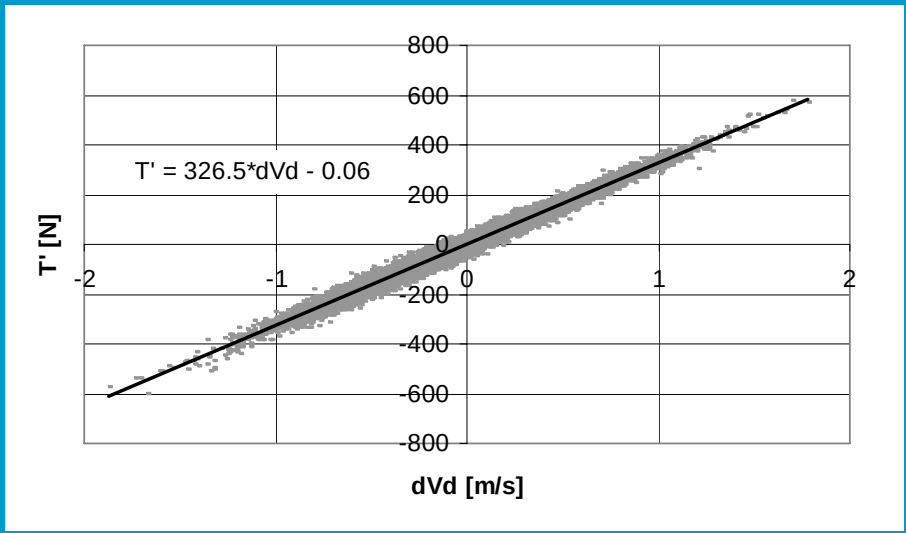
Changes in damping due to:

- Variable rotor speed ⟶ less damping (up to 25%)
- Drag term ⟶ more damping (up to 16%)

Garrad formula useful, but consider inaccuracy

Variable speed turbines
damping per blade element





V = 12 m/s

V = 23 m/s

Van der Tempel's method useful, but time consuming

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Variable speed turbines damping entire turbine

- Simplified closed-form

$$\xi_{aero}(V_0) = \Omega(V_0) \cdot \frac{N_b \, \rho \, C_{L_\alpha} \, m_{1b}}{4 \, M_0 \, \omega_n}$$

- Van der Tempel's method

$$\xi_{aero} = \frac{T'}{dV_d} \cdot \frac{1}{2 \, M_0 \, \omega_n}$$

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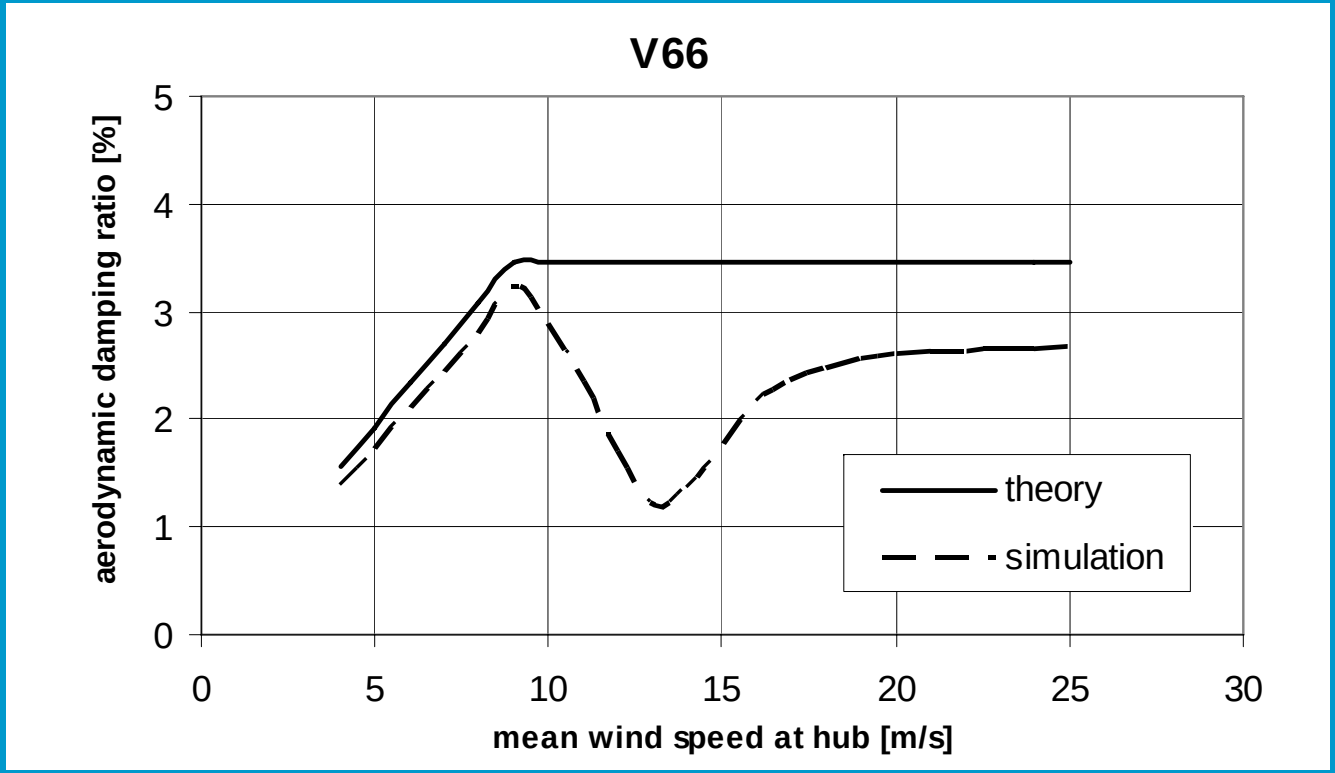
Variable speed turbines damping turbine 2 MW



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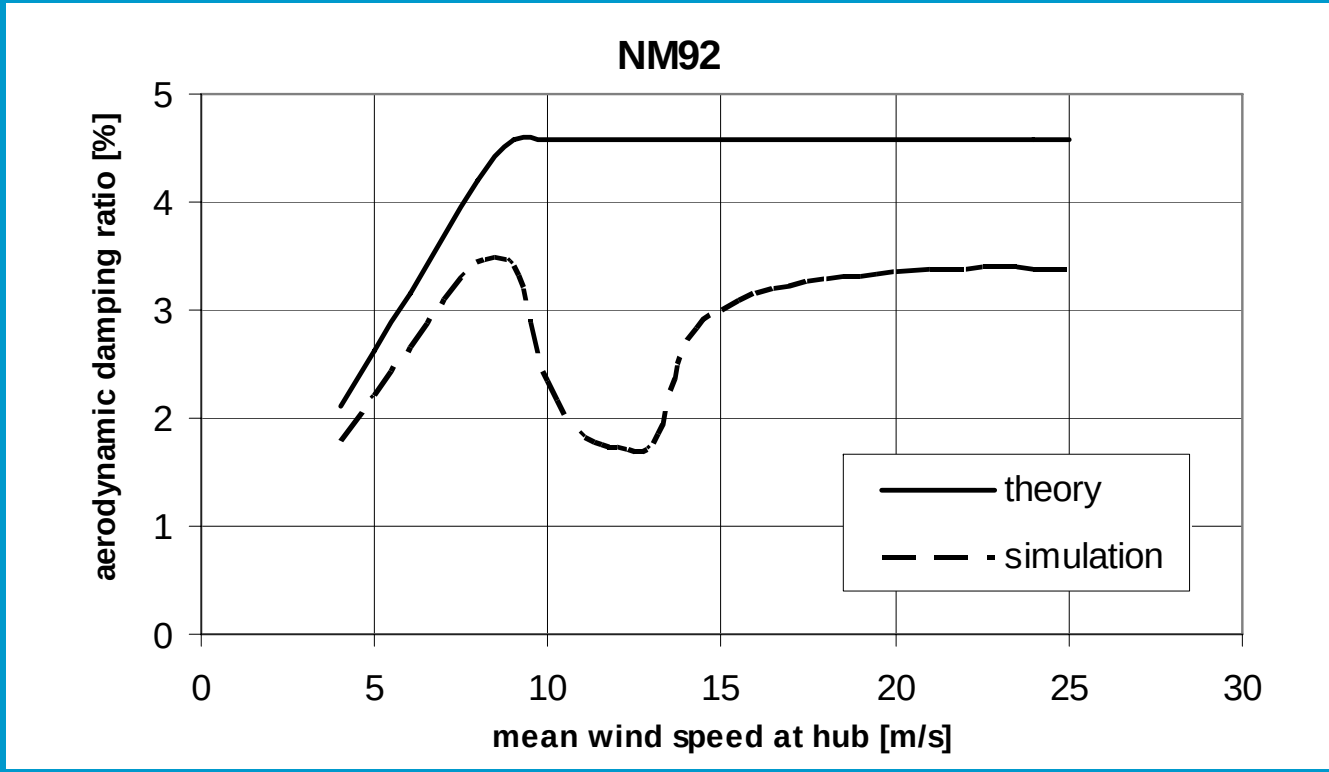
Variable speed turbines damping turbine 2.75 MW



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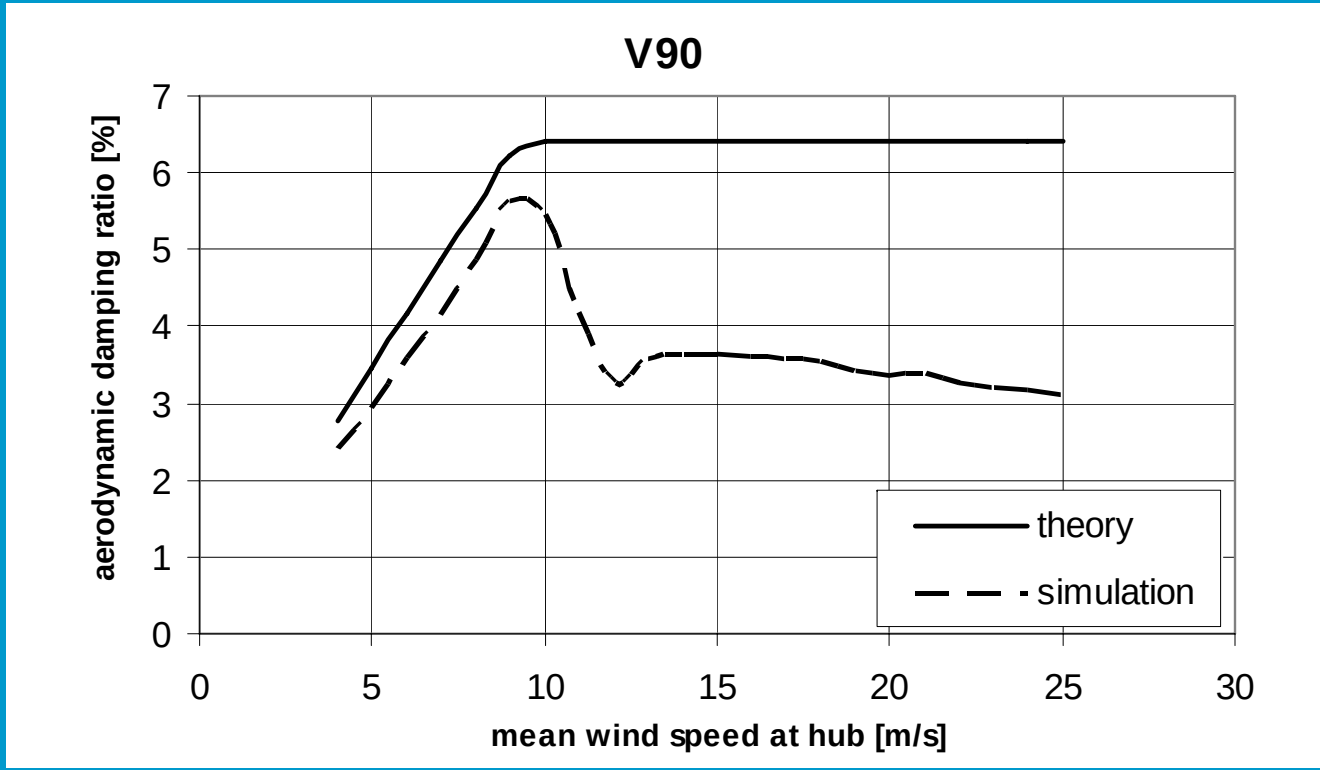
Variable speed turbines damping turbine 3 MW



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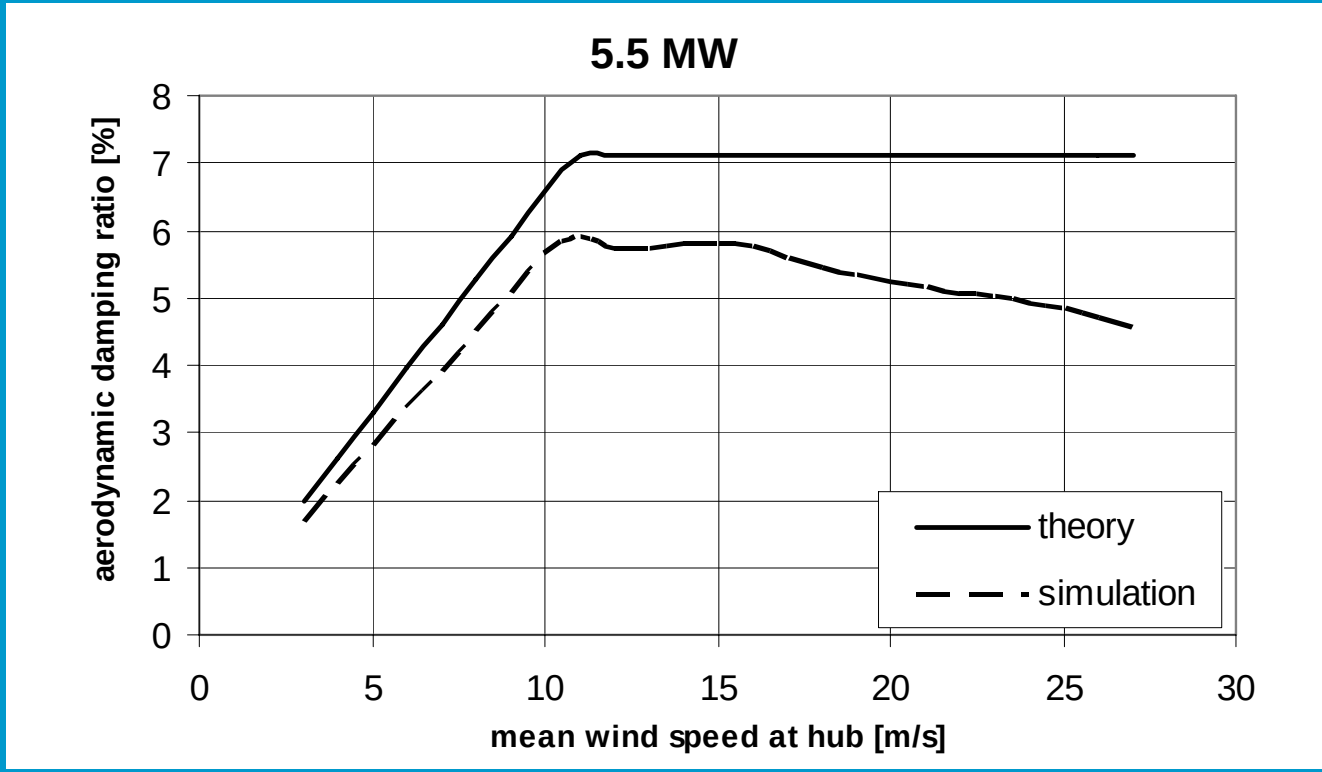
Variable speed turbines damping turbine 5.5 MW



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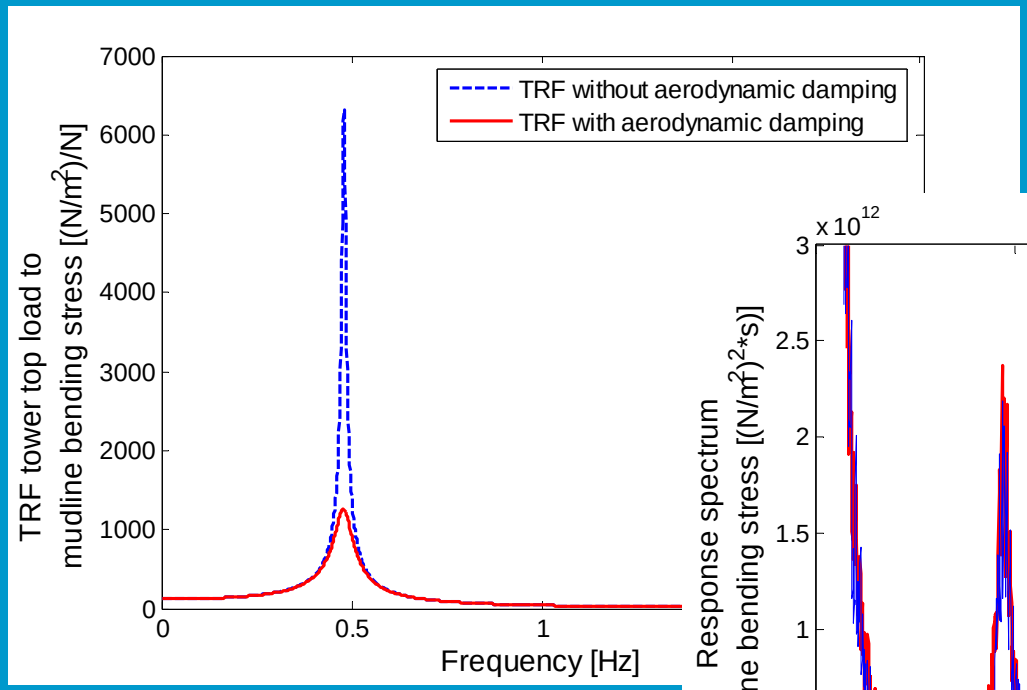
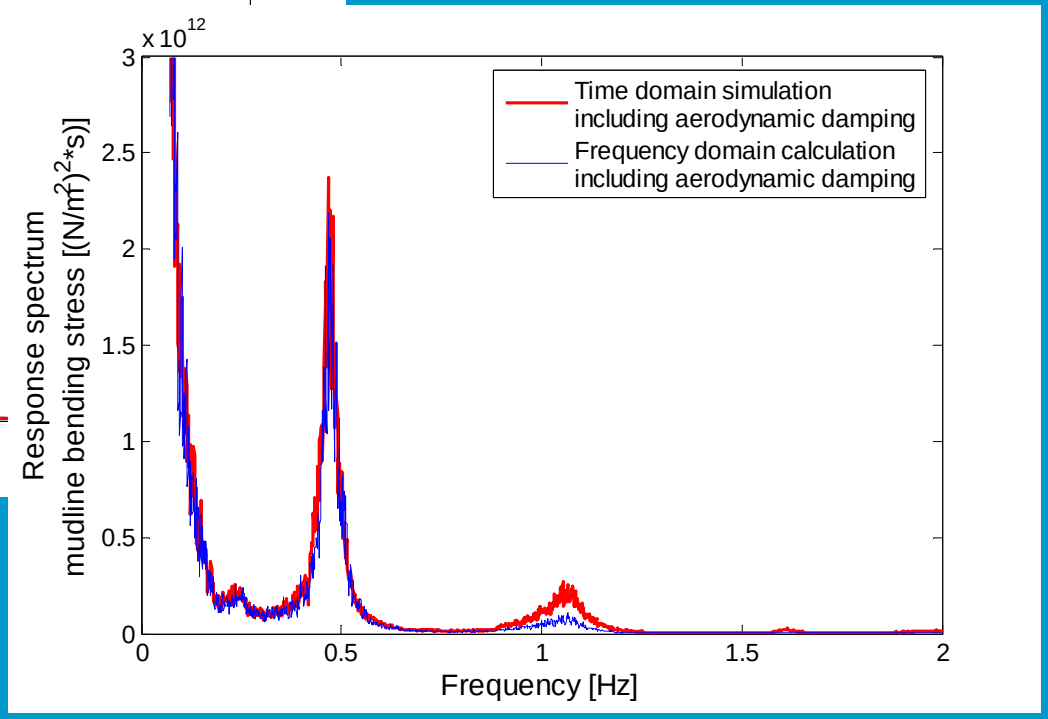
Evaluation





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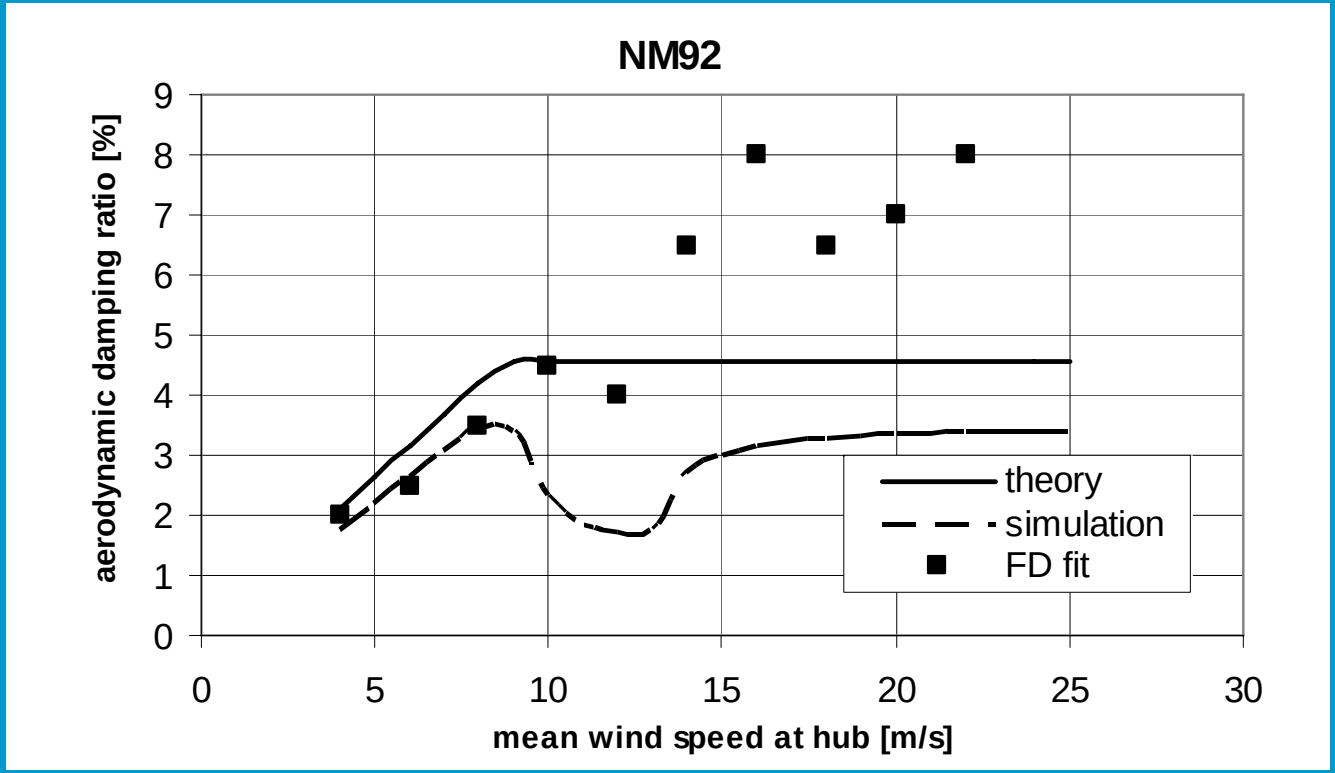
Evaluation



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Conclusions & Recommendations

- Constant speed turbines: OK
- Variable speed: significant differences
- Methods give good starting point

- Further investigation recommended