What is HAWCStab2?

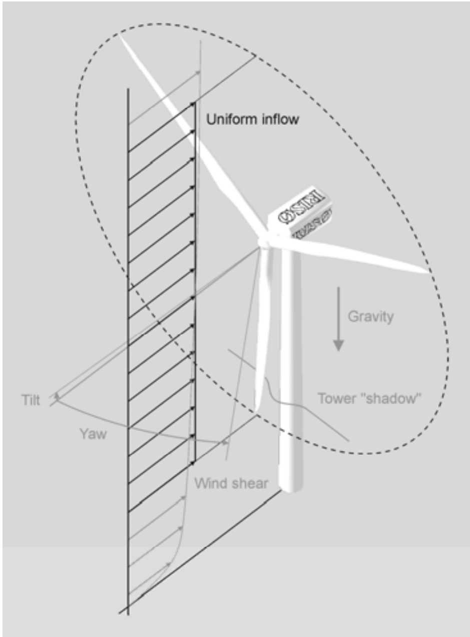
Linear aeroelastic model for eigenvalue and frequency domain analysis of wind turbines and blades

Nonlinear kinematics based on co-rotational elements with possibility of bearings e.g. generator and pitch.

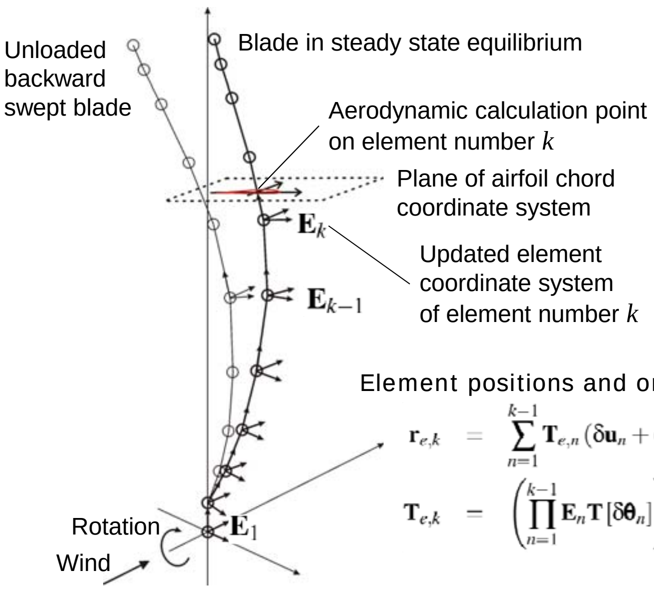
Uniform inflow to give a stationary steady state.

Analytical linearization about the stationary steady state.

Unsteady aerodynamics based on Leishman-Beddoes with a two state (per calc. point) model of dynamic inflow.



Nonlinear kinematic formulation

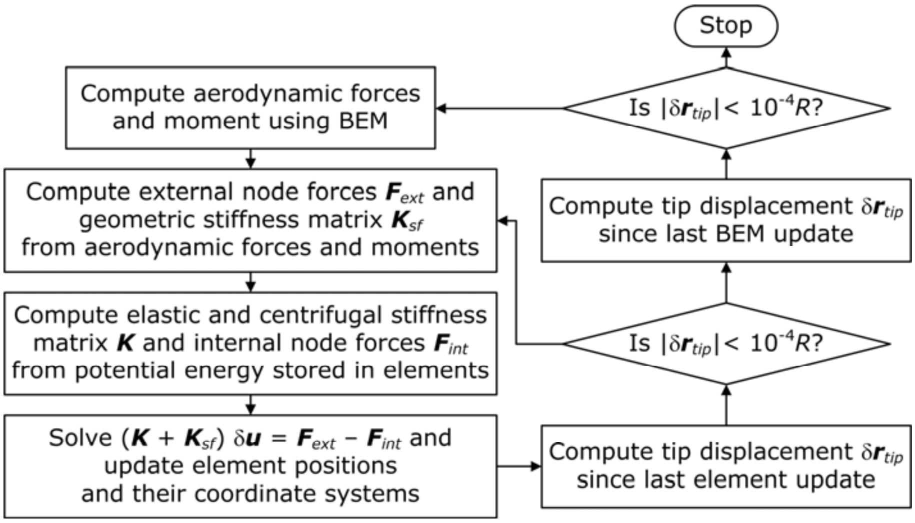


Element positions and orientations

$$\mathbf{r}_{e,k} = \sum_{n=1}^{k-1} \mathbf{T}_{e,n} \left(\delta \mathbf{u}_n + (l_n + \Delta l_n) \mathbf{e}_3 \right)$$

$$\mathbf{T}_{e,k} = \left(\prod_{n=1}^{k-1} \mathbf{E}_n \mathbf{T}[\delta \boldsymbol{\theta}_n] \right) \mathbf{E}_k$$

Nonlinear steady state



Linear equations for small vibrations about the nonlinear steady state

Structural mass
Structural damping
Gyroscopic forces
Aerodynamic damping
Elastic stiffness
Geometric stiffness of steady state force
Aerodynamic stiffness
Coupling to aerodynamic states

$$\mathbf{M}\ddot{\mathbf{x}}_s + (\mathbf{C} + \mathbf{G} + \mathbf{C}_a)\,\dot{\mathbf{x}}_s + (\mathbf{K} + \mathbf{K}_{sf} + \mathbf{K}_a)\,\mathbf{x}_s + \mathbf{A}_f\mathbf{x}_a = \mathbf{F}_s$$

$$\dot{\mathbf{x}}_a + \mathbf{A}_d\mathbf{x}_a + \mathbf{C}_{sa}\dot{\mathbf{x}}_s + \mathbf{K}_{sa}\mathbf{x}_s = \mathbf{F}_a$$

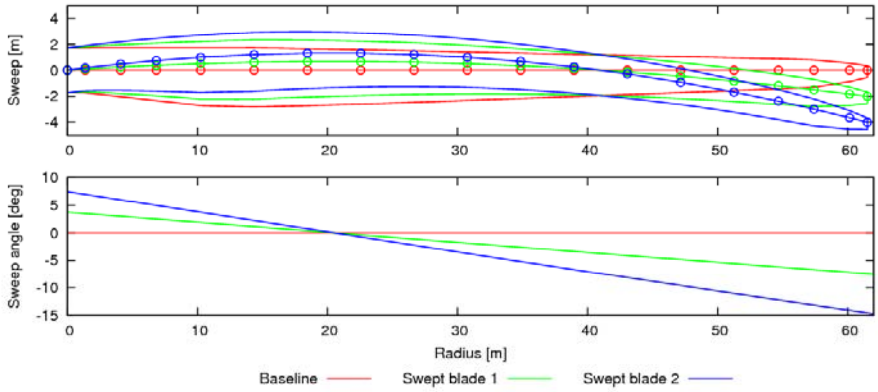
Time lags matrix
Coupling to structural states

$\mathbf{x}_s$ = elastic (and bearing) degrees of freedom

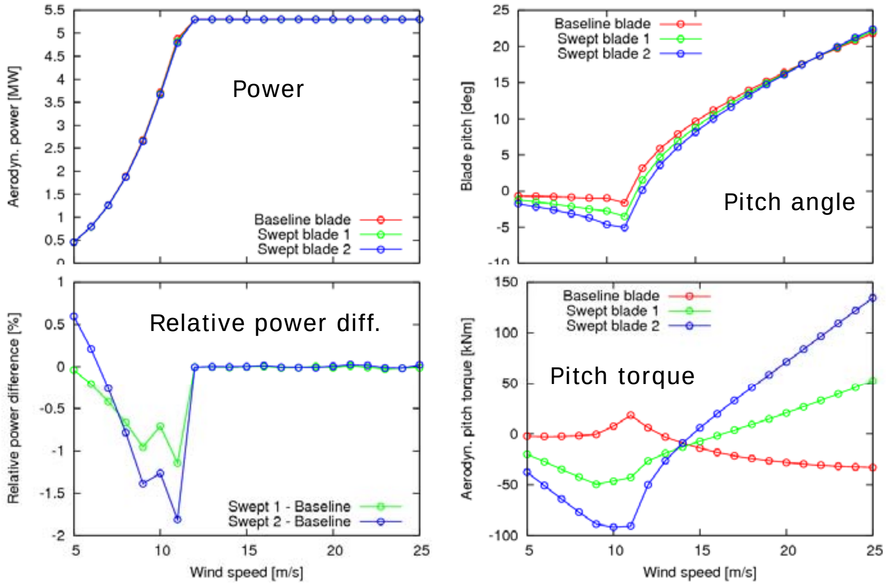
$\mathbf{x}_a$ = aerodynamic state variables

$\mathbf{F}_s, \mathbf{F}_a$ = forces due to actuators and wind disturbance

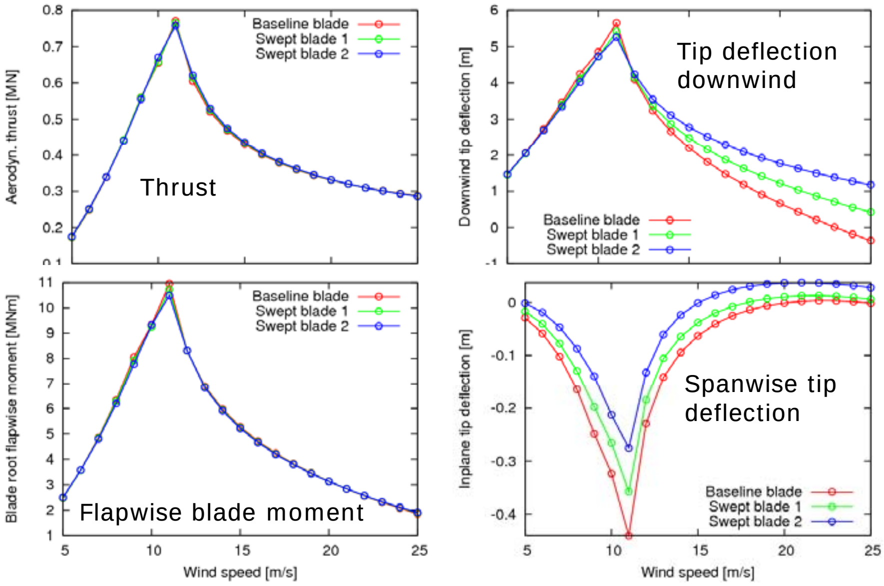
Backward swept blades
Baseline – NREL 61.5m with CG at EA



Steady state power and pitch angle & torque

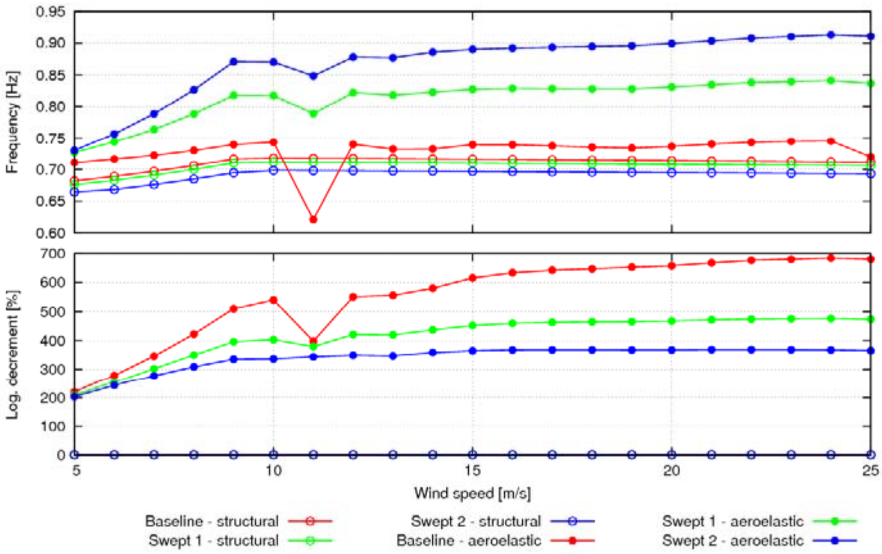


Steady state thrust and tip deflection



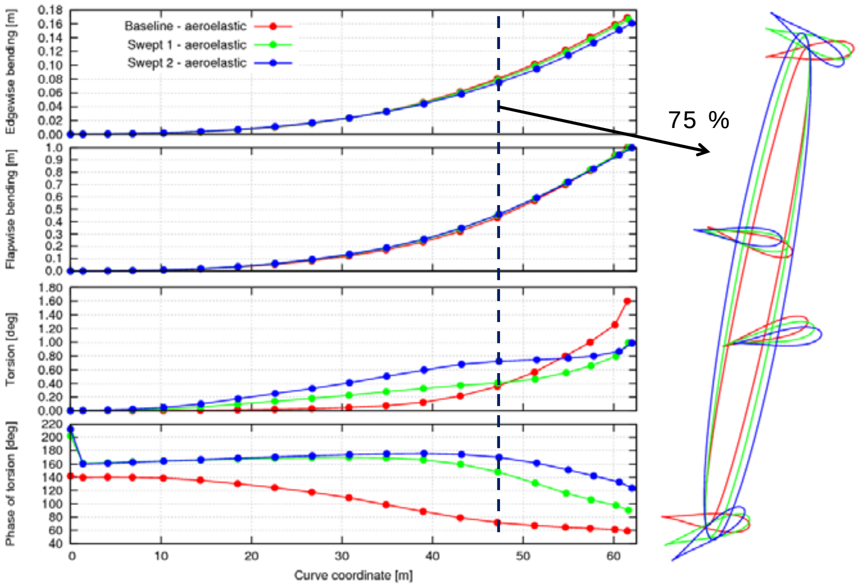
7 **Risø DTU, Technical University of Denmark** 49th AIAA Aerospace Sciences Meeting 2010

Modal frequencies and damping – 1st flap

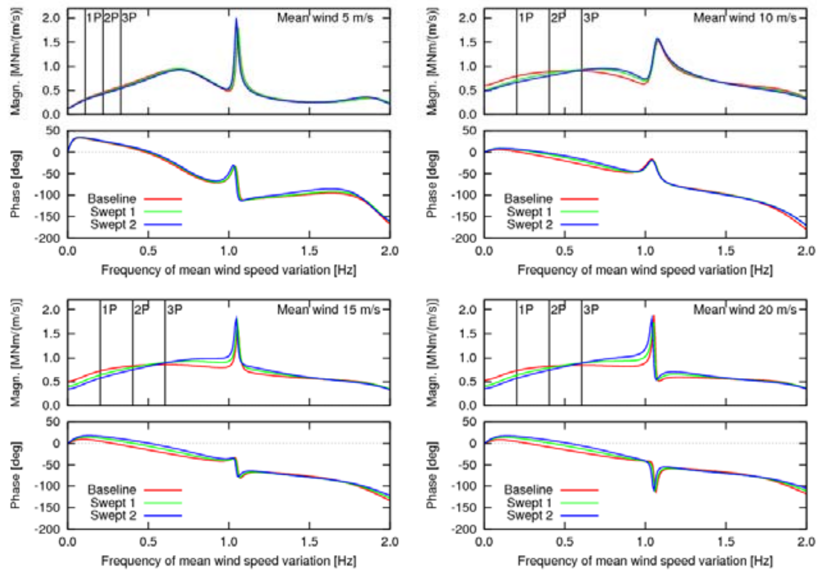


8 **Risø DTU, Technical University of Denmark** 49th AIAA Aerospace Sciences Meeting 2010

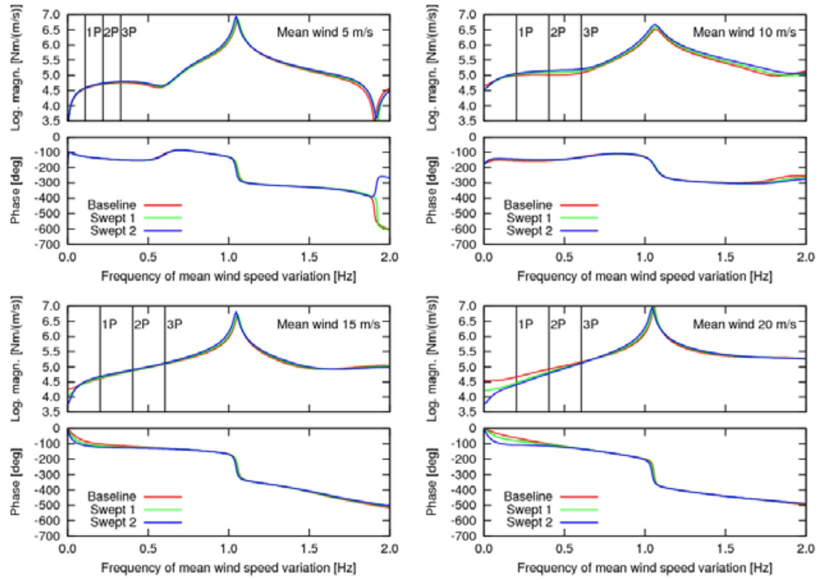
Aeroelatic flapwise mode shape at 10 m/s



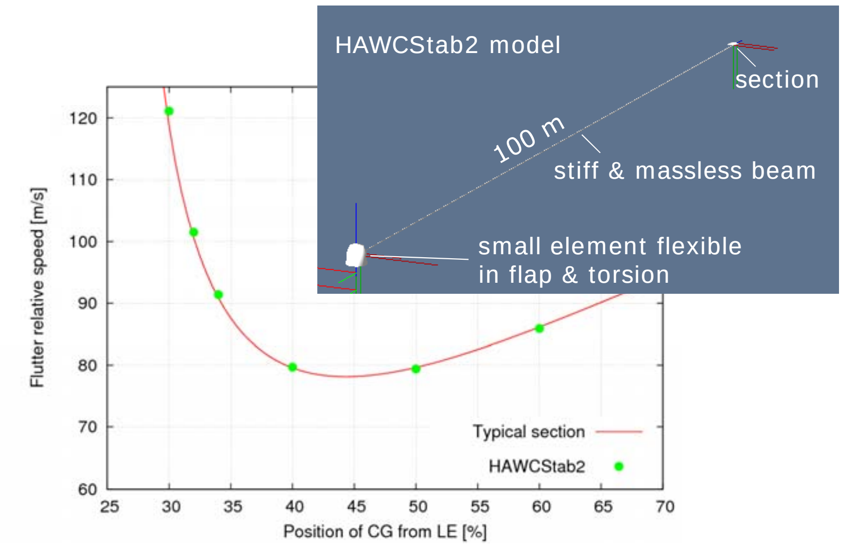
Flapwise blade root moment



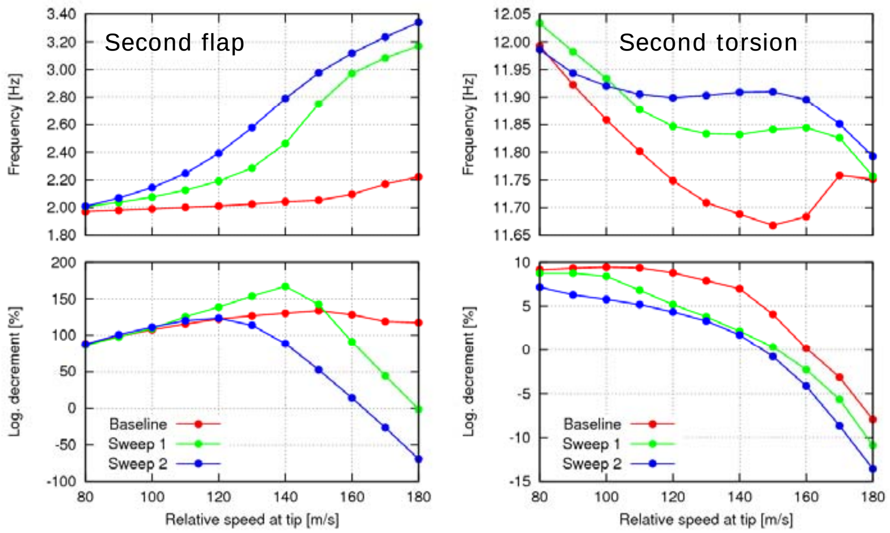
Edgewise blade root moment



Flutter test case – Typical Section analogy



Lowest damped modes for 0 deg pitch and increasing relative speed ($\lambda = \sqrt{99}$)



Conclusions

- Backward swept blades twist towards feathering for flapwise bending in both structural and aeroelastic first flapwise bending modes
- This structural coupling of bending and torsion leads to higher aeroelastic modal frequency and lower aeroelastic damping of this mode
- The increased flapwise frequency of a backward swept blade is caused by added aerodynamic flapwise stiffness due to the twisting towards feathering when bending downwind
- This increased flapwise stiffness lowers the frequency response of backward swept blades at frequencies below the first flapwise frequency which can explain the reduced fatigue loads observed in previous studies
- The previously reported slight increase in edgewise blade root loads of backward swept blades can be explained by a slight reduction of aeroelastic damping of the first edgewise bending mode
- The flutter limit in an overspeed situation seems to decrease with the backward sweep