A comparison of dynamic inflow models for the BEM

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The paper compares the results from four dynamic inflow models for BEM (ECN, Oye, TUD-VR and DTU) and the lifting line model AWSM with a dynamic wake development. The ECN model Eq.(1) is very similar to the Pitt and Peters model and that could be mentioned. The right hand side is the total force from all blades and thus the resulting velocity, u, at the rotorplane is the same for all blades. This may not be true in case of e.g., a wind shear. Also, for completeness the force on the right hand should be divided by Prandtl's tip loss correction to correct for a finite number of blades. This is of course done in the code as described in the text but should also be reflected when stating the equation.

In line 130 is stated that tau1 is the slow time constant and tau2 the faster one in the Oye model Eqs.(2-3). It is the exact difference. In the Oye model the time constants are given as

$$\tau_1 = \frac{1.1R}{(1-1.3a^*)V_o}$$

$$a^* = \min(0.5, a)$$

$$\tau_2(r) = (0.39 - 0.26 \cdot (r/R)^2) \cdot \tau_1$$

And it is important to limit the axial induction factor in the denominator for tau1. Was this done in the BEM code used in this work ? Instead of solving the Oye differential equations discretely as shown in Appendix 1 one can alternatively solve the ODEs as shown in Hansen [1] to get them in a more filter like form using exponential functions as the DTU model Eq. (7) and that may be numerically more robust.

All the BEM based dynamic inflow models except the ECN model has a radial dependency term in the filtering functions. Both the DTU and TUD-VR models contain empirically determined simple functions found from actuator disc simulations when changing the disc load.

When applying a dynamic inflow model the results can depend very much on whether the induced velocities are calculated on the blades or on a stationary grid as described by Helge et al. [2]. In wind shear the loads will vary over one revolution. The loads are high when the blades are pointing straight up and low when the blades are pointing down, but because the time constants in the dynamic inflow models are large compared to the time for one revolution the induced wind becomes quite constant over one revolution. If, however, the induced winds are computed on a stationary grid and afterwards interpolated to the blades the induced wind will also be consistently high at the top positions and thus also have a shear and giving a different azimuthal angle of attack variation. The computations done in this paper is mostly for a constant wind speed so this effect may not be very visible but could play a role in the simulations made for DLC1.2, where there is a shear exponent of 0.14.

To avoid the influence of the controller in section 2.4.2 time series of pitch and rotational speeds are first made without any dynamic inflow model and used for all models. Is this a good idea, since the purpose of the dynamic stall models is to have dynamically more realistic inflow ? It is mentioned that this is probably the cause of higher equivalent loadings in the results shown in Fig. 10. When the controller is free to determine the pitch and rotor speed when applying the various dynamic stall models the equivalent loads are reduced after rated wind speed as shown in Fig. B1 in the appendix. Please comment more

It is very characteristic that the Oye model gives results close to the ECN model except near the tip and that the DTU and TUD-VR seems very similar, see Fig. 3 and 4 for the pitch step change. That these two last models give a similar dynamic response is probably simply because they are both empirically based on AD simulations to determine the time constants. In Fig. 3 showing the dynamic response of the induced wind at 40%, 60%, 80% and 95% for a step input of pitch angle it looks as if the AWSM code has almost no radial dependency. If this result is correct, then the radial dependency functions used in many of the BEM applied dynamic wake models are too strong. Please comment.

There seems to be some challenges with the dynamic airfoil response using the shed vorticity in the AWSM model when comparing to the BEM simulations using Theodorsen, but this is addressed in the paper.

[1] Aerodynamics of wind turbines 3rd ed, Earthscan, Hansen MOL

[2] Madsen HA et al., Implementation of the blade element momentum method on a polar grid and its aeroelastic load impact, wind energy science, 5(1), pp 1-27, 2020