

Comparison of a Coupled Near and Far Wake Model With a Free Wake Vortex Code

Georg Pirrung, Vasilis Riziotis, Helge Madsen, Morten Hansen, and Taeseong Kim

General Comments

The specific research aims at formulating a fast but *advanced comprehensive* aerodynamic model for wind turbines. It combines a vortex based near wake with a BEM far wake modeling. In this respect it may be viewed either as a simplification of the lifting line model or as an improvement of BEM modeling. The simplification of the lifting line part consists of retaining only one quarter of the trailing vortices. For the remaining (far wake) part of the induction BEM modeling is used. Otherwise the concept of evaluating an effective angle of attack along with an effective relative velocity and then using look-up tables for the loads remains – as also done in full vortex methods. Finally in order to keep the cost low a number of numerical approximations are introduced.

The above general description applies to the original idea of Beddoes regarding the near wake and previous works by the authors on the far wake modeling. In this regard, the present contribution looks into the details of the model and ways to improve its performance in terms of numerical stability, cost and applicability.

Specific comments on the modeling

1. While keeping one quarter of the trailing vortices can be viewed as a compromise in order to have low cost, a comment should be added. For a 3 bladed wind turbine this choice prevents the blade to sense the wake of the preceding blade which may play a role at low wind speeds.
2. The split in X and Y components of W in eq (2) should be explained
3. Adopting eq (1) suggests that the expansion of the wake should be taken into account indirectly by adjusting the constants. Was this aspect considered?
4. In unsteady conditions the wake will also include radial vortex elements. Eq (15) intends to take into account the effect on the bound vorticity. In this eq the normal to the lifting line velocity v_r regulates the result. Does v_r correspond to the quasi-static set-up?
5. Since the near wake elements carry constant circulation, in unsteady conditions Kelvin's theorem will be violated. Was the option of switching to linear circulation distributions considered?
6. The CL slope of 2π originates from thin airfoil theory. This is not the case with thick airfoils. It would be interesting to check whether switching to different slope would improve the results.
7. The implementation contains several constants. The question is whether they depend on the blade design or they can be regarded as universal
8. It is clear that the main concern is to keep the cost low. How does the run time compare with a pure BEM simulation?

Specific comments on the results

1. Figure 12. If the simulations take into account the proper pitch, why is the margin to instability smaller at 25m/s? Could that be due to the fact that at 25m/s the wake is convected faster than in the case of 8m/s?
2. Full pitch steps: The discussion is based on two metrics: the slope of the axial force during the step and the post-step shape of the variation. With respect to the slope, the discussion could also include the angle of the spiral which should be bigger at more inboard stations. This may offer an additional explanation why BEM is in better agreement at $r=31\text{m}$ for both steps as compared to the far outboard section. Also the fact that the post step oscillations seen in the free-wake model do not appear in the coupled model simulations may suggest that the exponential approximations of the dynamics of the circulation (and angle of attack) act as filters in particular as regards the radial wake vortex elements (See previous point 4).
3. Partial pitch stepping: Although the load variation at $r/R=0.45$ is smooth in the coupled and free wake results as compared to BEM, the specific characterization may be misleading – smoothing is often connected to numerical damping or filtering while in the present case there is a physical mechanism that is driving this difference. The trailing vortex shed at the turning point will increase the incidence towards the root and decrease it on the other side.
4. Aerodynamic work computations: The results clearly indicate that BEM modeling is conservative (mainly with reference to Case 2 in Table 2 for which the results are not subjected to dynamic inflow modeling specifics). However the damping in the edgewise mode remains negative. Did the simulations only considered the rotor and how the specific result can be interpreted?

Concluding remarks

Improving BEM modelling is an never ending process. To my opinion including the near-wake model proposed by Beddoes is a valid research line. In this respect, the paper formulates specific improvements of this approach. This brings the specific modelling at a more mature level in particular with respect to stability analysis. The improvement in comparison to BEM modelling is supported by the results presented in the paper.

A lot of effort was put in keeping the cost low, so an average estimate of the cost should be added. Another point concerns the constants that are set. Are they universal? And if not, which of them could be subjected to calibration according to the authors' experience?