Evaluation of Gaussian wake models

LES simulation requires large amount of time and computational resources to resolve a wind turbine wake. Analytical wake models are faster but approximate. This overview compares four Gaussian models based on their ability to resolve a wake from single wind turbine.

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Gaussian models

Known values

- r, D — wind turbine radius and diameter
- C_T — thrust coefficient
- I_a — ambient turbulence

$\Delta\overline{U} = 1 - \frac{U}{U_\infty}$ — wake velocity deficit normalized by free flow velocity at hub height U_∞

Bastankhah & Porté-Agel (BPA) [1]

Early Gaussian model. Here, the version that considers ambient turbulence Ia is regarded. The model does not resolve wake field for $x/D<2$.

$$\Delta\overline{U} = F_{BPA1}(\sigma, C_T, D)exp(F_{BPA2}(\sigma, D, y, z))$$

where $\sigma = \sigma(k^*, x, \varepsilon), k^*$ is parametrized as $k^* = A + BI_a$.

Parameters: A, B

Jensen-Gaussian [2]

Top hat distribution in original Jensen model is replaced with Gaussian.

$$\Delta\overline{U} = F_{JG1}(\overline{U}^*)exp(F_{JG2}(r, \sigma))$$

where $\overline{U}^* = \overline{U}^*(k, x, a)$

Parameter: k

Ishihara [3]

Full-wake model with the

$$\Delta\overline{U} = F_{I1}(a, b, c, x, D)\ exp(F_{I2}(\sigma, D, y, z))$$

where a, b, c expressed as $\alpha_1 C_T^{\alpha 2} I_a^{\alpha 3}$. Coefficients for each variable may be fitted.

Double Gaussian [4]

Full wake model which captures double wake shape in the near wake region.

$$\Delta\overline{U} = c \cdot F(\sigma)\frac{1}{2}\{exp[f(r + r_0, \sigma)] + exp[f(r - r_0, \sigma)]\}$$

where $\sigma = (k^*, x^{1/3}, \varepsilon)$

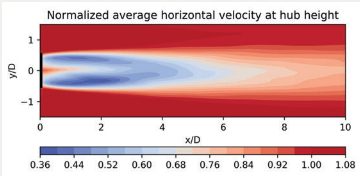
Parameters: k^*, ε, c

Methodology

A single NREL 5MW wind turbine is simulated with PALM LES code for free flow $U_0=10$ and $15\ m/s$ at hub height, neutral and stable conditions. The models are fitted to wake velocity profiles using least squares.

The following normalized velocity data sets are used:

- xy profiles at $x/D=1..10$
- rotor axis line
- xy hub height plane (control fit)



Factors to compare

- Number of parameters

Less parameters – easier to fit model, more parameters – more flexibility

- Tunability

Whether the original parameters can be tweaked for a better fit.

- Turbulence intensity

If included explicitly, the model can account different stability conditions.

- Wake approximation

Evaluated from root mean square error (RMSE)

- Wake shape

Axisymmetric or 2D wake, whether the near wake can be resolved as good as far wake

Summary

Spreading wake shape at $U_0=10\ m/s$ is challenging for the models, all except for Double Gaussian show high RMS error in near wake.

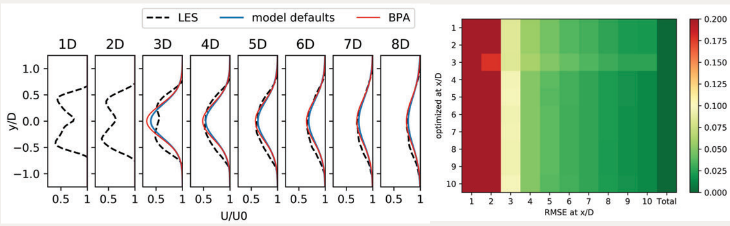
The wake at $U_0=15\ m/s$ is narrower and more uniform. All models provide good approximation of the full wake at high speed.

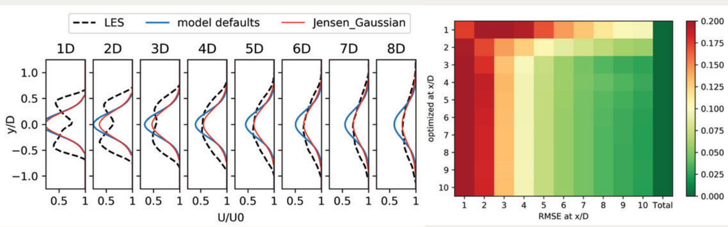
However, $U_0=10\ m/s$ is a typical wind speed for operating wind turbines. The approximation at $U_0=10\ m/s$ is more important. Unless a good resolution of near wake is required, all models can be used to approximate the far wake.

Double Gaussian model concept is in development and may go under revisions. **Ishihara** model is not supposed to be tunable, the recommended paramers also provide good approximation especially for the far wake.

Optimization for xy-wake profile (plots for x/D=8)

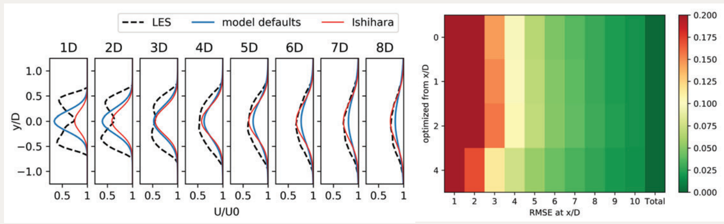
BPA and **Jensen-Gaussian** models perform best. The returned parameters are similar regardless which of the profiles $4<x/D<10$ was used for fitting.

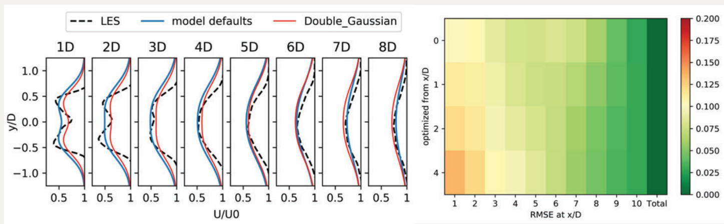




Optimization for rotor axis line

Full wake **Ishihara** and **Double Gaussian** models perform best, the data must be available for the full line. The fit is close to the one obtained from 2D plane.





Model	Ia	Full wake	# of par.	Tunable	2D wake
BPA	+	-	2	+	+/-
Jensen-Gaussian	-/+	-	1	+	-
Ishihara	+	+	9	-	+
Double Gaussian	-	+	3	+	+

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