Simplified upwind propagation model for wind turbines

Model description by Birger Plovsing and Jørgen Jakobsen (based on manuscript to be submitted to Noise Control Engineering Journal)

Input parameters

h_S: source height (m)

d: horizontal propagation distance (m)

u_{10}: wind speed component 10 m above ground in the direction of propagation (m/s), negative values in upwind

Fixed model parameters (cannot be changed)

h_R = 1.5 m: receiver height

z_0 = 0.05 m: roughness length

t_0 = 10° C: air temperature

$c(t_0)$ = 337,4 m/s: the sound speed at temperature t_0

Calculation of model parameter d'

Wind speed u (m/s) as a function of height z (m):

$$u(z) = u_{10} \ln\left(\frac{z}{z_0}\right) \Big/ \ln\left(\frac{10}{z_0}\right)$$

Average sound speed gradient $\Delta c/\Delta z$ (s^{-1}):

$$\frac{\Delta c}{\Delta z} = \frac{u(h_S) - u(h_R)}{h_S - h_R}$$

Effective sound speed c_0 (m/s) at the ground (z = 0) in linear sound speed profile approximation:

$$c_0 \cong c(t_0) + u_{10} - 10\frac{\Delta c}{\Delta z}$$

Relative sound speed gradient a (m^{-1}):

$$a = \frac{\Delta c}{\Delta z} \Big/ c_0$$

Distance to shadow zone d_{SZ} (m):

$$d_{SZ} \cong \sqrt{\frac{2h_S}{|a|}} + \sqrt{\frac{2h_R}{|a|}}$$

Horizontal propagation distance relative to shadow zone distance d' (dimensionless):

$$d' = \frac{d}{d_{SZ}}$$

Method for determining the A-weighted upwind ground effect ΔL_u in excess of the A-weighted downwind ground effect ΔL_g given in "Vindmøllebekendtgørelsen":

The excess A-weighted upwind ground effect ΔL_u in dB is calculated by:

$$h'_S = \begin{cases} 15 & \text{if } h_S \le 15 \\ h_S & \text{if } 15 < h_S < 70 \\ 70 & \text{if } h_S \ge 70 \end{cases}$$

$$k_1 = \frac{(h'_S - 15)}{220} + 0.55$$

$$k_2 = \frac{(h'_S - 15)}{50} + 2.1$$

$$\Delta L_u = \begin{cases} 0 & \text{if } d' \le k_1 \\ -15\dfrac{d' - k_1}{k_2 - k_1} & \text{if } k_1 < d' < k_2 \\ -15 & \text{if } d' \ge k_2 \end{cases}$$

Method for determining the upwind low frequency ground effect ΔL_{uLF} in excess of the one-third octave band downwind ground effect ΔL_{gLF} given in "Vindmøllebekendtgørelsen":

For one-third octave band frequencies below 31.5 Hz ΔL_{uLF} is equal to 0 dB.

In the frequency range 31.5 Hz to 160 Hz ΔL_{uLF} in dB is calculated by the following equation where ΔL_{max}, k_1 and k_2 are defined in the table below:

$$\Delta L_{uLF} = \begin{cases} 0 \quad if\ d' \leq k_1 \\ \Delta L_{\max} \dfrac{d' - k_1}{k_2 - k_1} \quad if\ k_1 < d' < k_2 \\ \Delta L_{\max} \quad if\ d' \geq k_2 \end{cases}$$

Frequency (Hz)	ΔL_{max}	k_1	k_2
31.5	-3	3	5
40	-6	2.3	5
50	-10	2	5.2
63	-14	1.7	5
80	-15	1.6	4.3
100	-15	1.5	3.6
125	-15	1.45	3.2
160	-15	1.35	3.05