

# Simplified upwind propagation model for wind turbines

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**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

$t_0 = 10^\circ$  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):

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

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  $a$  ( $\text{m}^{-1}$ ):

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

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 $\Delta L_u$ in excess of the A-weighted downwind ground effect $\Delta L_g$ given in “Vindmøllebekendtgørelsen”:**

The excess A-weighted upwind ground effect  $\Delta L_u$  in dB is calculated by:

$$h'_s = \begin{cases} 15 & \text{if } h_s \leq 15 \\ h_s & \text{if } 15 < h_s < 70 \\ 70 & \text{if } h_s \geq 70 \end{cases}$$
$$k_1 = \frac{(h'_s - 15)}{220} + 0.55$$
$$k_2 = \frac{(h'_s - 15)}{50} + 2.1$$
$$\Delta L_u = \begin{cases} 0 & \text{if } d' \leq k_1 \\ -15 \frac{d' - k_1}{k_2 - k_1} & \text{if } k_1 < d' < k_2 \\ -15 & \text{if } d' \geq k_2 \end{cases}$$

### **Method for determining the upwind low frequency ground effect $\Delta L_{uLF}$ in excess of the one-third octave band downwind ground effect $\Delta L_{gLF}$ given in “Vindmøllebekendtgørelsen”:**

For one-third octave band frequencies below 31.5 Hz  $\Delta L_{uLF}$  is equal to 0 dB.

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

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

Frequency (Hz)	$\Delta L_{max}$	$k_1$	$k_2$
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