Estimation of uncertainties due to the wind-induced noise in a screened microphone

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An outdoor sound measurement can be influenced by the noise induced by the wind at a screened microphone. This noise originates from turbulences that come from the direct interaction between the wind and the wind screen, as well as those generated by the interaction between the wind and the surrounding surfaces, especially the ground. The wind noise contribution introduces a bias in the measurement which depends on the noise source, the wind speed, and other parameters such as the ground roughness length or the atmospheric stability for example. We present here an estimation of this bias, as well as the uncertainties associated to this bias and dependant of some input parameters. These estimations were obtained using Monte Carlo simulations of wind-induced noise. Some practical applications are also presented.

1 Introduction

An outdoor sound pressure level measurement can be influenced by the noise induced by the wind at a screened microphone. This situation can be very common for example for experimental assessment of wind turbine noise. The contribution of the wind noise introduces a bias and an uncertainty on the result of the sound pressure level measurement, which both depend on the source noise level and on the wind characteristics (wind speed, atmospheric stability, …).

Nowadays, French standards of outdoor noise measurements do not consider this bias and this uncertainty, but just prohibit measurements if the wind speed is higher than 5m/s (see [1] for example). In some cases, this limit is either excessive or insufficient. We present here an estimation of the bias and of the uncertainty due to the influence of the wind noise at a screened microphone. The results allow to overcome the current wind speed limitation considered in the standards.

We first present on section 2 the wind-induced noise model used here, we present next the method used to estimate the bias and the uncertainty on the section 3. Some practical considerations are finally given on section 4.

2 Wind-induced noise in a screened microphone

2.1 Short review

The wind induced noise at a screened microphone originates from turbulences that come from the air flow around the microphone. The induced noise is more important at low frequency and this phenomenon has been addressed by several authors (see [2] for example for a clear review). Using a dimensional analysis Strasberg [3] shows that the pressure within a spherical or cylindrical windscreen with diameter D in a flow with mean velocity V depends on Strouhal number $Sr=fD/V$. This author proposed the following model of 1/3 octave frequency band sound pressure level :

$$L_{1/3}(f_m) = 40\log\left(\frac{V}{V_0}\right) - 23\log\left(\frac{f_m D}{V}\right) + 15 \quad (1)$$

where V_0 =1m/s is a wind speed reference, f_m is the median frequency of the 1/3 octave band and where log refers to the base-10 logarithm function. This model is nevertheless limited to low turbulence flows and then represent only the influence of the wake created by the windscreen. It is not realistic for describing the influence of atmospheric turbulences that are expected outdoors.

Using a different approach and writing the wind velocity as the sum of a constant (average) wind speed V and a fluctuating part u, Morgan and Raspet [4] write the rms pressure p as

$$p = \alpha\rho(Vu)^k, \quad (2)$$

where ρ=1.23 kg/m^3 is the air density, u is the rms value of wind fluctuations u, α and k are empirical coefficients that range respectively from 0.16 to 0.26 and from 1.0 to 1.3. After an analytical development, Zheng and Tan [5] found k=1, and $\alpha \leq 0.5$ for wind speeds lower than 2-12 m/s and windscreen of 4-20cm. However, this model does not specify if the origin of wind fluctuations comes from wake or from atmospheric turbulences.

In order to provide a model adequate for outdoors, van den Berg has specifically investigated the contribution of atmospheric turbulences on the wind-induced noise in a screened microphone [2]. He found that this contribution is dominant over the wake contribution described by the previous authors and that the atmospheric contribution is therefore the main cause of the wind noise at a screened microphone. This wind noise model has been validated with several experimental data. This model will be used in the following and is described in the next section.

2.2 The van den Berg wind noise model

Using (2) with k=1, the sound pressure level is written as [2]

$$L_{at}(u) = 20\log(\alpha\rho Vu / p_0), \quad (3)$$

where p_0=20µPa. u is the rms wind speed fluctuations due to atmospheric turbulences and V is the mean wind speed. Atmospheric turbulence is created by thermal convection and by friction that results from wind shear. In the atmospheric boundary layer, the mean wind speed is written

$$V = (u_* / \kappa)\left[\ln(z / z_0) - \Psi\right], \quad (4)$$

where κ=0,4 is von Karman's constant, z_0 is the roughness height and u_* is the friction velocity. ψ is a stability function that depends on height z and on L the so-called Monin-Obukhov length that describes the stability of the atmosphere. It is given by (see [6] for example):

$$L = -u_*^3 T_0 \rho C_p /(kgH), \quad (5)$$

where C_p is the specific heat capacity of the air at constant pressure, g is the acceleration due to gravity, T_0 the air temperature and H is the sensible heat flux. The stability function ψ is written [6]

- $L > 0$ (stable atmosphere):

$$\Psi = -5z / L \tag{6}$$

- $L < 0$ (unstable atmosphere):

$$\Psi = 2\ln[(1+x)/2] + \ln[(1+x^2)/2] - 2\tan x + \pi/2 \tag{7}$$

with $x = (1-16z/L)^{1/4}$.

The rms wind speed u related to atmospheric turbulences is given using a Kolmogorov spectrum (for fz/V>>1/33):

$$u^2 = 0{,}3u_*^2 (V/z)^{2/3} f^{-5/3}. \tag{8}$$

Using equations (6) and (4) with (3), van den Berg gives the following wind-induced 1/3 octave sound pressure level [2]:

$$L_{at,1/3}(f_m) = 40\log(V/V_0) - 6{,}67\log(f_m D/V) - 10\log\left[1+(f_m/f_c)^2\right] + F(z) + C(\alpha) \tag{9}$$

with

$$f_c = V/(3D),$$
$$F(z) = -20\log\left\{(z/D)^{1/3}\left[\ln(z/z_0) - \Psi\right]\right\}, \tag{10}$$
$$C(\alpha) = 20\log(0.215\,\kappa\alpha\rho V_0^2 / p_0).$$

For α=0.25, C=62,4dB. For octave band levels $L_{at,1/1}$ the constant C must be replaced by C+4,8 [2]. The low frequency characteristic of wind-induced noise is represented in Figure 1.

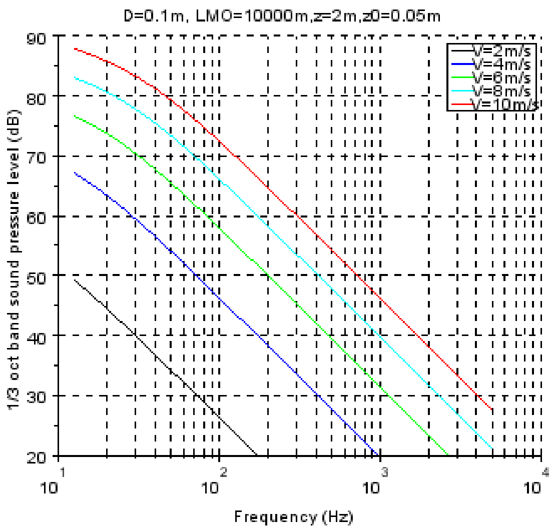

Figure 1: 1/3 octave band spectrum of wind-induced sound pressure level, for wind speed V=2, 4, 6, 8 and 10 m/s (α=0.5).

An expression of the broadband A-weighted sound pressure level can also be obtained by A-weighting and by integrating equation (9) over all 1/3 octave bands [2]:

$$L_{at,A} = 69{,}4\log(V/V_0) - 26{,}7\log(D/l_0) + F(z) + C(\alpha) - 74{,}8 \tag{11}$$

where l_0=1m is a reference length.

Figure 2 shows that for a same wind speed, the wind-induced sound pressure level is higher at low height, because atmospheric turbulences are more important near the ground.

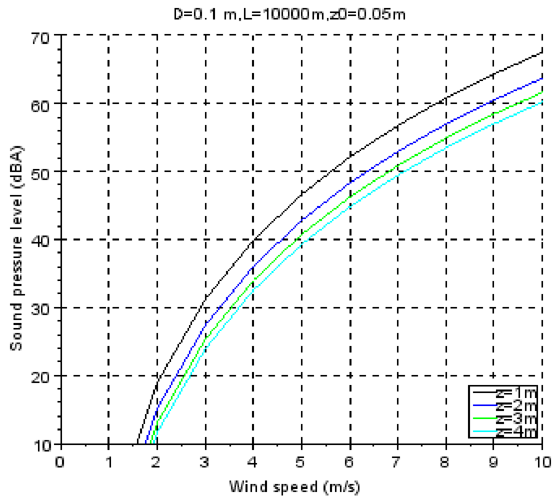

Figure 2: A-weighted broadband wind-induced sound pressure level, for height z=1, 2, 3 and 4 m (α=0.5).

3 Experimental uncertainties due to wind-induced noise

3.1 Estimation of the sound contribution of a source

During an outdoor experimental assessment of the noise level of a source, a common problem is to estimate the sound contribution of the source without taking into account other disturbing sound contributions. For windy conditions, the measured sound pressure level L_{mes} results from a combination of the sound contribution of the source and of the unwanted contribution of the wind. The contribution of the wind noise introduces a bias b to the measurement result which is equal to

$$b = L_{mes} - L_{source} \tag{12}$$

with

$$L = 10\log\left(10^{L_{wind}/10} + 10^{L_{source}/10}\right) \tag{13}$$

where L_{wind} and L_{source} are the sound contributions of the wind and of the source respectively. Because of uncertainties on some input parameters of the bias model (see below), an uncertainty is associated with the estimation of this bias. The sound level contribution of the source is estimated with the bias-corrected sound level L_c, with its uncertainty:

$$L_c = L_{mes} - b \pm d.u_b . \quad (14)$$

where *-b* is the bias correction and u_b is the standard uncertainty of the bias. *d* is the coverage factor that depends on the confidence level that is chosen and of the shape of the probability density function of the bias. The value of *d*=1,95, relative to a normal distribution and to a 95% confidence interval, is often considered.

3.2 Estimation of the bias and of its uncertainty

The bias and its uncertainty are estimated using a Monte Carlo method [7]. It consists here in estimating the probability density function (PDF) of the bias with 10^5 evaluations of equation (12), calculated from 10^5 independent random values of some uncertain input parameters (see below). The mean and the standard deviation of the PDF give respectively an estimate of the average bias *b* and of the standard uncertainty u_b. The main step of the method is the calculation of equation (12) and (13) where the wind-induced noise contribution L_{wind} is calculated with the wind model described in section 2.2 (equation (9) or (11)).

Calculations have been done for several wind speed classes: inside each class, the uncertain parameters of the bias model were the atmospheric stability ψ, the wind speed and the sound level contribution of the source. The atmospheric stability function ψ was considered to be totally unknown and was estimated with equations (6)-(8) and thanks to random samplings of heat flux from -150 Wm^{-2} to 700 Wm^{-2}, and of air temperature ranging from -20°C to 40°C, covering all common situations in Europe. The sound source contribution is also considered to be totally unknown and ranges from 15 dB(A) to 80 dB(A). All random samplings of uncertain parameters were done according to a uniform law.

The bias correction ˇ*b,* and its associated uncertainty, are given for a 9 cm windscreen on Figure 3 and Figure 4, as a function of the A-broadband measured sound level. As expected, for each wind speed class the uncertainties increase as the measured sound level decreases, becoming infinite when the measured sound level tends to the wind sound level contribution. For a wind speed class, the bias correction also increases as the height increases, because the wind-induced noise is more important near the ground (see section 2.2).

The results presented here are for a A-weighted broadband sound level approach, but the same kind of methodology has been applied for spectrum bias corrections if an octave or a 1/3 octave bands analysis is required (equation (9) must then be used for the wind noise model).

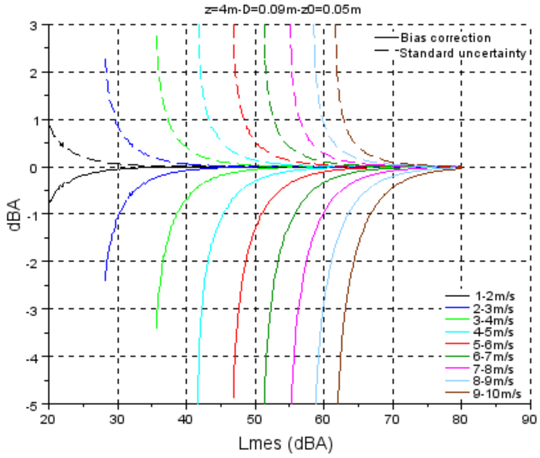

Figure 3: A-weighted broadband bias correction (solid lines) and standard uncertainty (dashed lines), as a function of the measured sound level, for z=4m, D=0.09m, α=0.5 and for several 1m/s wind classes.

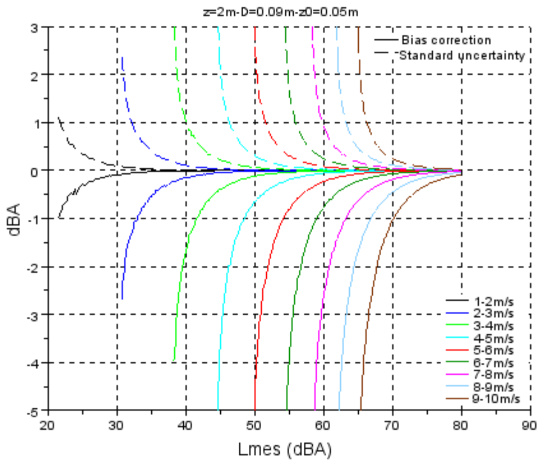

Figure 4: A-weighted broadband bias correction (solid lines) and standard uncertainty (dashed lines), as a function of the measured sound level, for z=2m, D=0.09m, α=0.5 and for several 1m/s wind classes.

4 Practical application

The bias correction must not be considered in every cases. When the wind noise contribution dominates the sound contribution of the source, it can be risky to apply a bias correction because of the uncertainty that becomes infinite. In these situations, it is better to exclude data. On the opposite, when the sound source dominates the wind contribution, the bias correction and its uncertainty become negligible and no bias correction is necessary. Such situations have been identified on Figure 5 for a practical use: domain (1) is for situations where bias and uncertainty are negligible (*b*<0,1 dB(A) here), domain (2) is for situations where the uncertainty is too high (u_b>5 dB(A) here). Experimental data related to domain (2) must be excluded. The bias correction and its uncertainty must therefore be considered only for data that are between those two domains.

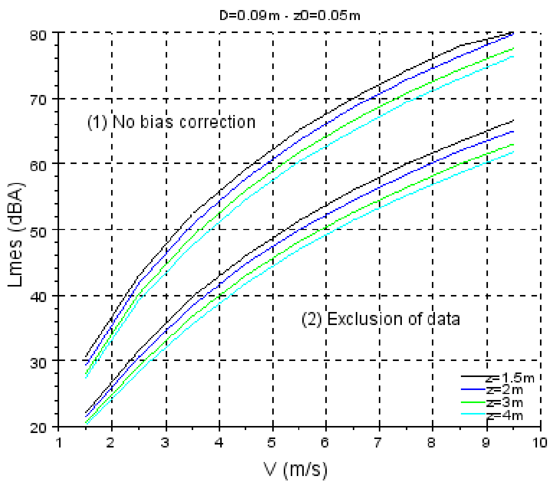

Figure 5: areas for the application of the bias correction, for 4 heights z (α=0.5). Domain (1): the bias correction can be neglected, domain (2): the bias correction uncertainty tends to infinity.

Notice that the current wind speed limitation of 5 m/s given in the French standards (see [1] for example) is not adequate in several cases: even if wind speed is lower than 5 m/s, the influence of the wind-induced noise can be significant (*e.g.* V=4m/s and *Lmes*=45dB(A), see Figure 5). Moreover, the current limitation is adequate, without considering any bias correction, only for measured sound pressure level higher than 55-60dB(A).

5 Conclusions and outlooks

A method for estimating the uncertainties due to the wind-induced noise on a screened microphone has been investigated. Some Monte Carlo simulations have provided bias and uncertainty to be considered to estimate the sound level contribution of a source when measurements take place outdoors during windy conditions. The bias and uncertainties presented here cover most common atmospheric situations in Europe. The uncertainties can be reduced if some parameters, such as atmospheric stability or roughness length, are explicitly measured. Some refinement of the method can also be considered, especially for the hypothesis of the probability density functions of uncertain input parameters which have been considered here to be gaussian.

The efficiency of a wind screen is characterized in the wind noise model by the empirical quantity α given in equation (3). The results presented here are valid for α=0.5 which is considered to be a common value [2]. For non common wind screen, specific measurements must be necessary to estimate accurately this quantity.

A limitation of the method presented here is given by a limitation of the Monin-Obukhov theory that supposes the ground to be horizontally homogeneous. Therefore, if this method may not be suitable for site with a lot of tall obstacles around the receiver, it can be applicable however for many wind turbine sites.

The method allows now to overcome the current wind speed limitation considered in French standards. It will be included in the next French standard on environmental acoustics uncertainties [8]. It nevertheless requires the measurement of the wind speed close to the microphone. Current research is focusing on an experimental campaign to validate the method.

Acknowledgments

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