2. EDITION

EXPERT GROUP STUDY
ON

# RECOMMENDED PRACTICES FOR WIND TURBINE TESTING AND EVALUATION

# 4. ACOUSTICS MEASUREMENT OF NOISE EMISSION FROM WIND TURBINES

2. EDITION 1988

*Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems*

# RECOMMENDED PRACTICES FOR WIND TURBINE TESTING

# 4. ACOUSTICS. MEASUREMENT OF NOISE EMISSION FROM WIND TURBINES

## 2. EDITION 1988

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## Foreword

The evaluation of wind turbines must encompass all aspects of a Wind Energy Conversion System (WECS) ranging from: energy production, quality of power, reliability, durability and safety, through to cost effectiveness or economics, noise characteristics, impact on the environment and electromagnetic interference. The development of internationally agreed evaluation procedures for each of these areas is needed now to aid in the development of the industry while strengthening confidence and preventing chaos in the market.

It is the purpose of the proposed recommendations for wind turbine testing to address the development of internationally agreed test procedures which deal with each of the above noted aspects for characterizing wind turbines. The IEA expert committee will pursue this effort by periodically holding meetings of experts, to define and refine consensus evaluation procedures in each of the areas:

1. Power Performance
2. Cost of Energy from WECS
3. Fatigue Evaluation
4. Acoustics
5. Electromagnetic Interference
6. Structural Safety
7. Quality of Power
8. Glossary of Terms

This paper addresses the fourth item - Acoustics - and updates the previous publication produced in 1984. The recommendations will be regularly reviewed in the light of the latest knowledge, and areas requiring further investigation will be identified.

# List of Contents

## Introduction

The purpose of this guide is to recommend sound measurement procedures which would enable noise emission of a wind turbine to be characterized. This involves using measurement methods appropriate to noise emission assessment at locations close to the machine, in order to avoid errors due to anomalous sound propagation, but far enough away to allow for finite source size. The procedures described are different in some respects from those that would be adopted for sound propagation in community noise studies. They are intended to facilitate wind turbine noise characterization in a manner suitable for input to noise propagation calculations and for comparisons with the technical specification of a given machine. Standardization of measurement procedures will also facilitate comparisons between different wind turbines.

Several levels of technical capability are allowed for in the guide, depending on the type of wind turbine, but even at the minimum capability level it is expected that good quality measuring equipment will be available or alternatively, assistance can be obtained from a regulatory, research or commercial organization.

## Scope and Field of Application

This document describes the procedures to be used for the measurement and description of the noise emission of wind turbines. The primary goal of the document is to facilitate comparisons of noise measurements made in different countries by different investigators. The secondary goal is to provide an engineering data-base for the development and validation of analytical acoustic prediction techniques.

The document does not address the psycho-acoustic aspect of the acoustic problem, nor does it attempt to define acoustic limits of acceptability for regulatory purposes.

# RECOMMENDED PRACTICE FOR MEASUREMENTS OF NOISE EMISSION

## 1. DEFINITIONS

### 1.1. A-weighted sound pressure level, $L_{pA}$, in decibels:

The value of the sound pressure level determined using frequency-weighting network A (see IEC Publication 651, reference [1]). The reference sound pressure is 20 $\mu$Pa.

### 1.2. Equivalent continuous sound pressure level, $L_{eq,T}$, in decibels:

Value of the sound pressure level of a continuous steady sound that, within a specified time interval T, has the same mean square sound pressure as a sound under consideration whose level varies with time. It is given by the formula

$$L_{eq,T} = 10 \lg \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)}{p_o^2} dt \right] \tag{1}$$

where $L_{eq,T}$ is the equivalent continuous sound pressure level, in decibels, determined over a time interval T starting at $t_1$, and ending at $t_2$,

$p_o$ is the reference sound pressure in micropascals (= 20 $\mu$Pa),

p(t) is the instantaneous sound pressure of the noise signal in micropascals.

### 1.3. Equivalent continuous A-weighted sound pressure level, $L_{Aeq,T}$, in decibels:

Value of the A-weighted sound pressure level of a continuous, steady sound that, within a specified time interval T, has the same mean square sound pressure as a sound under consideration whose level varies with time. It is given by the formula

$$L_{Aeq,T} = 10 \lg \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p_A^2(t)}{p_o^2} dt \right] \tag{2}$$

where $L_{Aeq,T}$ is the equivalent continuous A-weighted sound pressure level, in decibels, determined over a time interval T starting at $t_1$ and ending at $t_2$,

$p_o$ is the reference sound pressure (20 $\mu$Pa),

$p_A(t)$ is the instantaneous A-weighted sound pressure of the sound signal.

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*Note:* In American ANSI-standards, the equivalent continuous A-weighted sound pressure level is called the average sound level with the symbol $L_{eq}$.

### 1.4. A-weighted percentiles $L_{10}$, $L_{90}$ and $L_{95}$ in decibels:

The percentile $L_n$ is defined as the A-weighted sound pressure level that over a specified time is exceeded n per cent of the time. In this document, the percentiles $L_{10}$, $L_{90}$ and $L_{95}$ are used.

### 1.5. Reported standard sound level, $L_{std}$, in decibels:

The value of the equivalent continuous A-weighted sound pressure level corrected to a slant distance of 100 m according to equation (4).

# 2. INSTRUMENTATION

## 2.1. Instruments

### 2.1.1. Equipment for the determination of the equivalent continuous A-weighted sound pressure level.

This equipment shall meet the requirements of a type 1 sound level meter according to IEC Publication 651, reference [1]. The microphone shall have the maximum diameter of 13 mm.

Additional requirements for the sound level meter are that the equipment shall be capable of providing a read-out display or have the facility to be able to obtain the equivalent continuous A-weighted sound pressure level.

If the noise is steady over the period of interest, the measurements may be carried out with equipment that cannot register the true equivalent continuous sound pressure level. In this case the metered "slow" response should be used. The reading should be taken as the average meter deflection. If the meter reading fluctuates over a range greater than 5 dB, the noise is not considered to be steady.

### 2.1.2. Equipment for the determination of the A-weighted percentiles $L_{10}$, $L_{90}$ and $L_{95}$

In addition to the requirements given in clause 2.1.1., the equipment shall be capable of providing a read-out of, or otherwise have the facility to obtain the A-weighted percentiles $L_{10}$, $L_{90}$ and $L_{95}$ with the time weighting "F" (fast) according to IEC 651.

### 2.1.3. Equipment for the determination of third-octave band spectra

In addition to the requirements given in clause 2.1.1., the equipment shall have a substantially constant frequency response over at least the frequency range 45 Hz to 5600 Hz. The filters shall meet the requirements of IEC Publication 225, reference [2].

The equipment shall be capable of providing a read-out of the equivalent continuous sound pressure level in third-octave bands with centre frequencies from 50 Hz up to 5000 Hz.

### 2.1.4. Equipment for the determination of narrow band spectra

In addition to the requirements given in clause 2.1.1., the equipment shall have a substantially constant frequency response from 45 Hz up to 5600 Hz.

For analyzers with constant absolute bandwidth, the noise bandwidth (the effective bandwidth) shall be not wider than approximately 7 Hz for frequencies below 2000 Hz and not wider than approximately 70 Hz for frequencies above 2000 Hz. For analyzers with constant relative bandwidth (constant percentage bandwidth), it shall be possible to choose a noise bandwidth in the region of 3% (1/24 octave).

The averaging time shall be at least 2 minutes and the average shall be taken of at least 100 spectra.

## 2.2. Microphone with reflecting surface and windscreen

The microphone shall be mounted on a hard board with the diaphragm of the microphone in the vertical plane and with the axis of the microphone pointing towards the wind turbine, see Figure 1. The board shall have an area of at least 1.5 m × 1.8 m and be made from a material that is acoustically hard, e.g., a piece of plywood or hard chip-board with a thickness of at least 16 mm. The board shall be placed on the ground with its long sides pointing towards the wind turbine.

The windscreen to be used together with the ground-mounted microphone consists of a primary and, where necessary, a secondary windscreen. The primary windscreen consists of one half of an open cell foam wind screen with a diameter of approximately 90 mm, which is centered around the diaphragm of the microphone, see Figure 1. The secondary windscreen should be used when necessary to obtain an adequate signal-to-noise ratio in high winds. It consists of a wire hemispherical frame, at least 450 mm in diameter, which is covered with a 25 mm layer of open cell foam with a porosity of 4 to 8 pores per 10 mm. This secondary hemispherical windscreen shall be placed symmetrically over the smaller, primary windscreen.

## 2.3. Recording of data

When data are stored on tape as an essential part of the measuring procedure, any additional errors caused by the process of storing and replay shall be taken into account when presenting the result of the measurement.

## 2.4. Calibration

The complete measurement chain must be calibrated at least at one frequency before and after the measurements. An acoustic calibrator with an accuracy of ± 0.5 dB shall be used.

# 3. MEASUREMENTS

## 3.1. Measuring positions

Five microphone positions are to be used. Four positions shall be laid out in a pattern round the wind turbine with the fifth position further downwind as indicated in Figure 2. The distance from the wind turbine to each microphone position shall be that indicated in Figure 2 with a tolerance of ± 20%. The reference distance $R_o$ is given by (see also Figure 3):

$$R_o = H + D/2 \tag{3}$$

where, for a horisontal axis wind turbine,

H is the distance from ground to centerline of rotor shaft,

D is the diameter of the rotor.

For a wind turbine with a vertical axis

H is the highest point of the structure,

D is the equatorial diameter.

The microphone shall normally be mounted on a large board which is positioned on the ground, see clause 2.2. When the propagation path to the wind turbine is obstructed or when it is impractical to use a ground microphone position, e.g. for off-shore wind turbines, a microphone without a board and at the height of 5.0 m may be used.

The measurement position shall be chosen so that the influence of reflecting structures (e.g. buildings) is minimized.

## 3.2. Acoustic measurements

### 3.2.1. Equivalent continuous A-weighted sound pressure level

The equivalent continuous A-weighted sound pressure level shall be determined at the five measuring positions and during the following conditions:

A. Wind turbine in operation

A1. Wind speed as close to cut-in as possible,

A2. Wind speed as high as possible.

B. Wind turbine parked

B1. Wind speed as close as possible to the wind speed during the A1 measurement.

The difference in wind speed during the conditions given by A1 and A2 shall be at least 3 m/s.

Each measurement is recommended to be at least 2 minutes in duration where practicable and during periods of steady wind. Remarks on subjective impression of noise (audible discrete tones, impulsive character, spectral content, temporal characteristics, etc.) should be noted.

Measurements shall be carried out simultaneously at the reference position and at least at one of the other points.

### 3.2.2. Measurements at the reference position

In addition to the measurement of the equivalent continuous A-weighted sound pressure level, the following quantities shall be determined at the reference position:

a) the equivalent continuous sound pressure level in third-octave bands with centre frequencies from 50 Hz up to 5000 Hz,

b) the A-weighted percentiles $L_{10}$, $L_{90}$ and $L_{95}$,

c) in the case of audible pure tones, a narrow band spectrum covering the appropriate part of the frequency spectrum.

It is recommended that the measurement time period in case a) is at least 15 sec for each frequency band and in case b) is at least 2 minutes.

These measurements shall be carried out at a wind speed as near cut-in + 2 m/s (measured at hub height) as possible.

## 3.3. Non-acoustic measurements

During the measurements specified in clause 3.2. the following wind turbine related parameters shall be continuously recorded:

- wind speed and direction at hub height. The wind speed should preferrably be obtained from measurements of the power produced and the measured power versus wind-speed curve. In the second place it can be measured with an anemometer at hub height and in the third place at 10 m height. The anemometer and wind direction transducer must be located upwind the wind turbine and not closer than 1.5 rotor diameters for horizontal-axis machines and 2 rotor diameters for vertical-axis machines and not farther than 6 rotor diameters. During the course of the test, the anemometer must never be in the wake of any portion of any wind turbine rotor or structure (Ref [3]).
- power output,
- rotor speed,

and optionally also

- blade pitch angle,
- yaw angle.

Also to be recorded every ½ hour are:

- relative humidity,
- temperature,
- barometric pressure,
- turbulence (qualitative assessment). If equipment to measure the turbulence is not available, the following parameters should be reported: time of day, cloud cover and terrain type. The turbulence can then be estimated approximately from these parameters combined with windspeed,
- the possible presence of a temperature inversion in the atmosphere.

# 4. DERIVED RESULTS

## 4.1. Reported standard sound levels

As specified in clause 3.1., the measuring positions may differ from $R_o$ and $2R_o$ respectively by ±20%. There are also two alternative microphone heights of 0 m and 5 m. In order to obtain comparable results, the equivalent continuous A-weighted sound pressure levels shall be corrected to a reference distance and, when appropriate, to a measurement point on the ground according to the following equation:

$$L_{std} = L_{Aeq,T} + 20\,\lg(R_i/R_N) - K, \qquad (4)$$

where $L_{std}$ is the reported standard sound level, in decibels,

$L_{Aeq,T}$ is the measured equivalent continuous A-weighted sound pressure level, in decibels,

$R_i$ is, in the case of a horizontal axis wind turbine, the distance from the measurement position to the centre of the rotor. In the case of a vertical axis wind turbine, $R_i$ is the distance from the measurement position to a point at the axis of rotation midway between the upper and lower blade attachments, see also Figure 3,

$R_N$ is the reference slant distance, = 100 m,

K is 0 dB with microphone on the ground according to clause 2.2.,

3 dB when the alternative microphone height of 5 m has been used.

If a single value of the 5 values obtained according to equation (4) is reported, this value shall be the maximum value.

# 5. ADDITIONAL INFORMATION TO BE RECORDED

## 5.1. Characterization of the wind turbine

The geometric configuration of the wind turbine and its operating conditions must be completely specified. The wind turbine configuration should be described in detail and should include such information as rated capacity, principal dimensions, hub height, tower type, rotor dimensions and geometry, number of blades, upwind or downwind, overspeed controls, fixed or variable pitch blade angle, teetering rotor, yaw configuration, generator type, geartooth frequency, etc.

## 5.2. Acoustic environment

The following information on the acoustic environment at and near the site of the wind turbine and the measuring positions shall be recorded:

a) type of topographic terrain (hilly, flat, cliffs, mountains, etc., for nearest 1–2 km). Photographs should be included,

b) type of ground (grass, sand, etc.),

c) nearby reflecting structures such as building structures and sound sources such as trees, bushes, water surfaces, etc.,

d) other nearby sound sources such as other wind turbines, highways, industrial complexes, airports etc., which may affect the background level.

## 5.3. Instrumentation

- The equipment used for the measurements, including type, serial number and name of manufacturer,
- frequency response of instrumentation system,
- bandwith of narrow band frequency analyzer.

## 5.4. Acoustic data

- The locations and orientation of the microphone at each measurement position,
- the corrections in decibels, if any, applied in each frequency band for the frequency response of the microphone, frequency response of the filters in the pass band, background noise, nicrophone height, etc.,
- the reference distance $R_0$.

# 6. INFORMATION TO BE REPORTED

In addition to the data specified in clause 3–5, the following information should appear in the test report:

a) **Identification of wind turbine**

The test report should contain a complete description of the wind turbine which was tested. Information to be included should contain a description (and if appropriate, a diagram) of the appearance of the wind turbine, its conventional operating characteristics, and the performance characteristics of the machines which may relate to noise. The power curve should be included.

b) **Wind turbine operating procedure**

A description of how the wind turbine is operated under test is an essential part of the report. If the device is operated in any manner other than its conventional operating mode, this operating procedure should be completely described.

c) **Acoustic data**

The reported standard sound levels from the five measurement positions rounded to nearest whole decibel. The third-octave band spectra and the percentiles obtained at the reference point.

d) **Measurement uncertainty**

The section on measurement uncertainty should give some indication of the degree of confidence which can be placed in the measurement results. This could be expressed in terms of standard error, confidence limits, or some other appropriate statistical factor.

e) **Time and date**

Time and date when the measurements were performed.

## 7. ACKNOWLEDGEMENTS

The present edition of this document has been developed through a series of meetings with participants from different countries participating in the IEA R&D-agreement. The following persons have participated with valuable contributions at these meetings

B. Andersen and J. Jakobsen, Denmark,
J. van der Toorn and L. van Schie, The Netherlands,
A. Robson, R. Dunlop and A. R. Henderson, United Kingdom,
S. Meijer, Sweden.

The appendices have been written by S. Meijer and A. Gustafsson (No 1), B. Andersen (No 2), J. Jakobsen (No 3), S. Ljunggren (No 4) and A. Gustafsson and S. Meijer (No 5).

During the work leading to this revision, an informal contact has been maintained with the acoustics subcommittee of the American Wind Energy Association (AWEA). This contact has resulted in a certain co-ordination of the present IEA document with a future AWEA/ANSI standard. It has not been possible to obtain perfect co-ordination, but it is thought that the similarities are fundamental enough to render comparisons possible between measurement results obtained using the two procedures.

## 8. REFERENCES

[1] IEC Publication 651. Sound level meters.

[2] IEC Publication 225. Octave, half-octave and third-octave band filters intended for the analysis of sound and vibrations.

[3] Expert Group Study on Recommended Practices for Wind Turbine Testing & Evaluation: 1. Power Performance Testing; Edited by Sten Frandsen; B. Maribo Pedersen, submitted to Executive Committee (the International Energy Agency Programme for Research & Development on Wind Energy Conversion Systems). 2. Edition 1988.

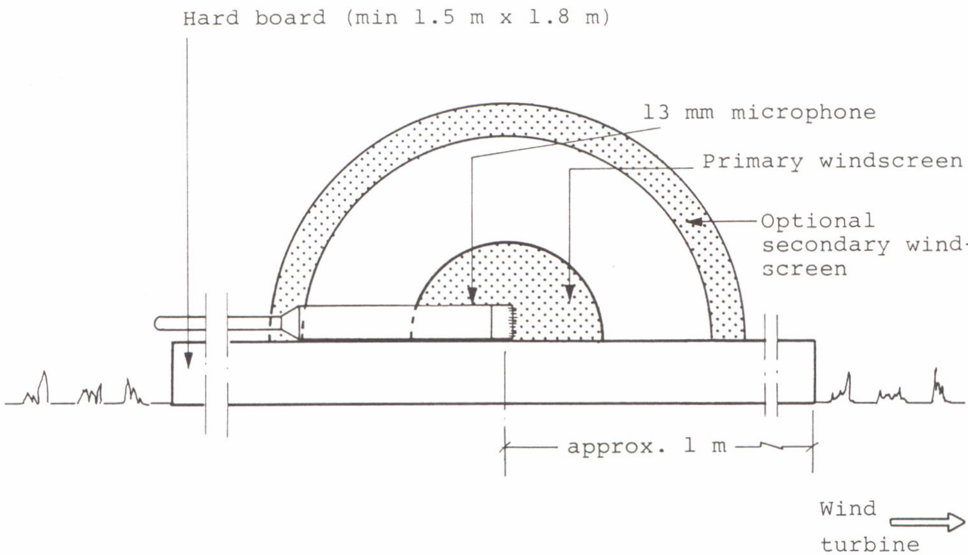



*Figure 1. Mounting of microphone. (Not to scale)*

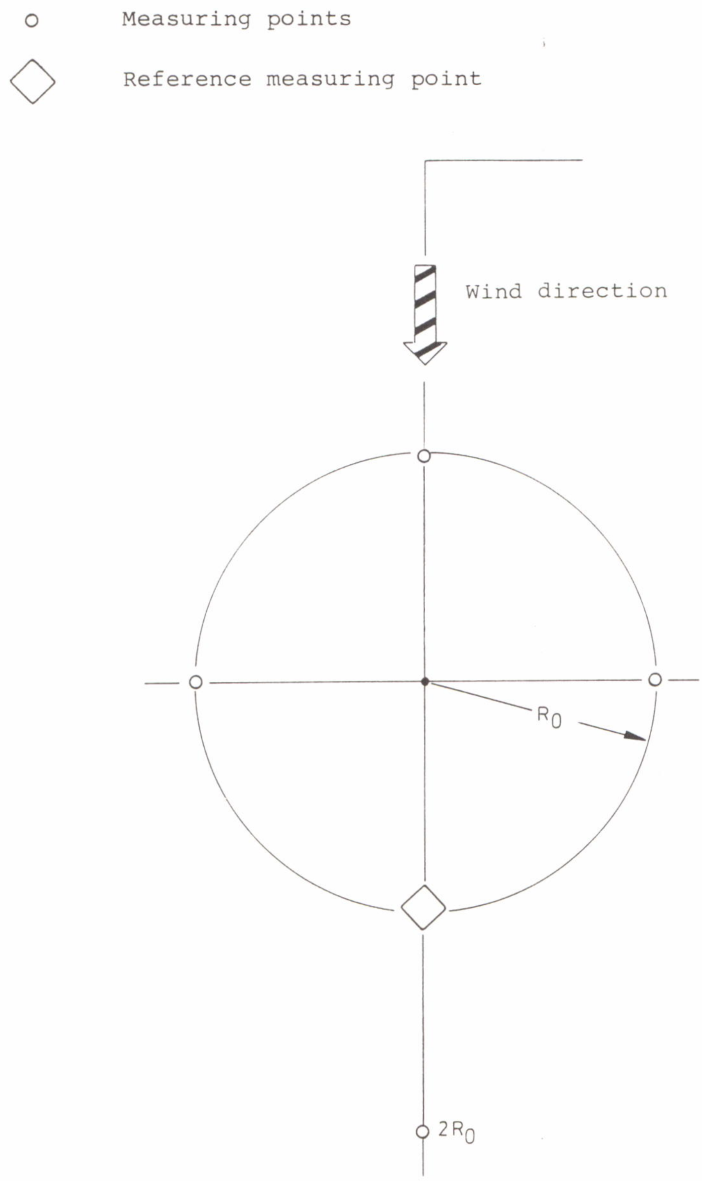
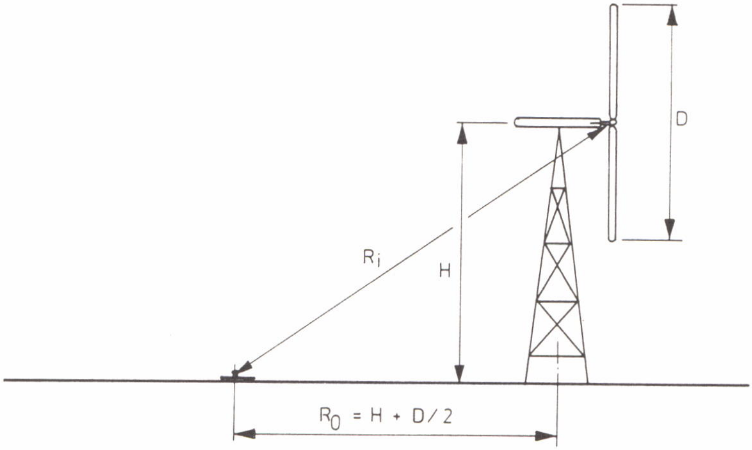
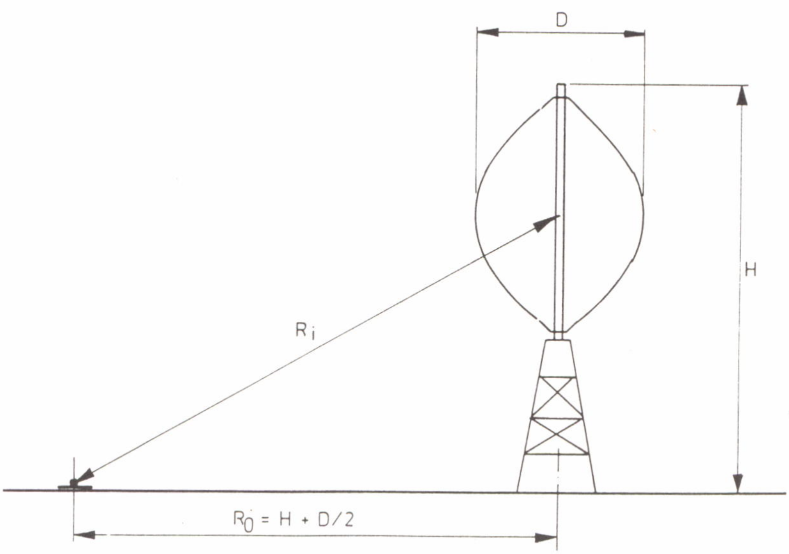



*Figure 2. Recommended pattern for measuring points.*




a)




b)

*Figure 3. Illustration of the definitions of $R_o$ and $R_i$ for a) horizontal-axis turbine*
*b) vertical-axis turbine*

# APPENDIX 1.

## SUPPLEMENTARY MEASUREMENTS RECOMMENDED FOR TURBINES WITH PERIODIC UNSTEABY BLADE LOADS

An impulsive, thumping, sound may by heard from wind turbines with periodic, unsteady loads on the rotor blades. These unsteady loads can be due to a number of causes e.g. wakes from support tower structural members for downwind and vertical axis turbines. The sound pressure level spectrum contains distinct spectral peaks at harmonics of the blade passage frequency.

To assess, in a simple way, whether noise from the wind turbine exhibits impulsive behaviour a method described in [1] can be used. In this method the pressure signal is filtered in a 31.5 Hz centre frequency, 1/1 octave band filter and converted to a d. c. voltage by a precision sound level meter operating in the "fast" response mode. The signal is displayed on a stripchart recorder or on a spectrum analyzer with a time domain display. It is often easier to discern the impulsive behaviour of the noise from the filtered signal than from the unfiltered one.

Narrow band spectra for the frequency range $f_L$ to 100 Hz, where $f_L$ is in the interval 10 Hz–20 Hz, and with a bandwidth smaller than half the blade passage frequency should be determined and reported together with examples of time series traces of the pressure signals.

The characteristics of the impulsive sound can be influenced by the local atmospheric conditions and as a consequence of this the sound measurements should if possible be made after sunset.

Wind conditions, measurement points and recording of non-acoustic data should be as specified in the main text.

### Reference


[1] Kelley N. D. A Suggested Method for Field Assessment of Impulsive Noise Characteristics of Wind Turbines prepared for the Acoustics Standards Committee, American Wind Energy Association, May 11, 1987.

# APPENDIX 2.

## THE EFFECT OF THE MICROPHONE MOUNTING METHOD ON THE MEASURED SOUND PRESSURE LEVEL

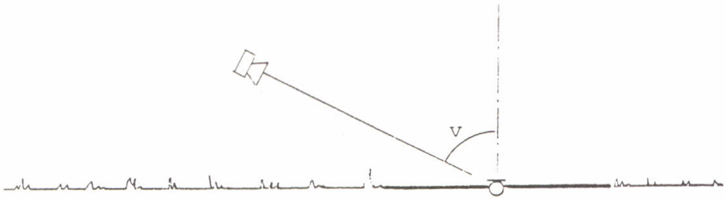
The effect of the hard board was tested in a small experiment, where noise from a reference sound power source (B&K 4205) was measured by two microphones on the board (one flush mounted, the other "parallel"-mounted). The hard board was placed upon a lawn. Immediately after these measurements the microphone systems were placed in a large anechoic chamber (without the board, noise incidence in the plane of the microphone membranes-angle of incidence = 90°). Figure 1 a, b and c shows the difference between the ⅓-octave band levels measured upon the hard board and in free field with the angle of incidence as parameter.

The deviations from the expected +6 dB can be explained by the impedance jump approximately 1 m in front of the microphones.

The effect of simply laying the microphone upon the hard board ("parallel"-mounted), instead of actually flush-mounting it, was investigated using a B&K 4134 pressure microphone flush mounted and a B&K 4165 free-field microphone "parallel"-mounted in the above mentioned experiment. In the case of the "parallel"-mounted microphone, the microphone was mounted with an azimuth angle towards the source of either 90° og 0°.

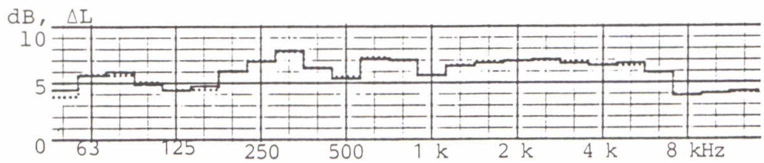
Figure 2 shows roughly the two mounting-methods, while Figure 3 shows the error using the "parallel"-mounting method. The figure shows the difference between the ⅓-octave band levels measured with the flush-mounted and the "parallel"-mounted microphone. The full line corresponds to noise incidence in the membrane plane of the "parallel"-mounted microphone (azimuth angle 90°).

For an angle of incidence in the range 30°–60° (in the vertical plane) the error at 8 kHz will be -1 dB to -7 dB using a "parallel"-mounted microphone pointing towards the sound source.



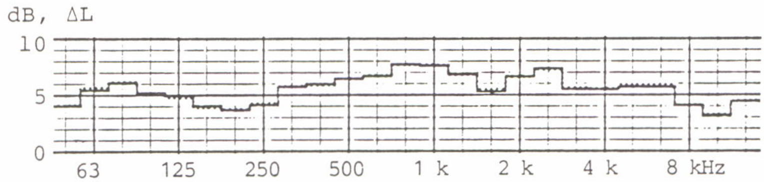

a)

v = 30°




b)

v = 75°




c)

v = 75°

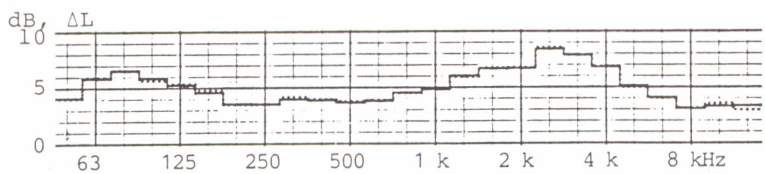



*Figure 1: Difference (ΔL) between ⅓ octave band spectra of noise from reference sound power source measured with a flush-mounted microphone upon the hard board on a lawn and the same microphone in free field (anechoic chamber).*
*v indicates the angle of sound incidence and ... a repetition of the measurement.*

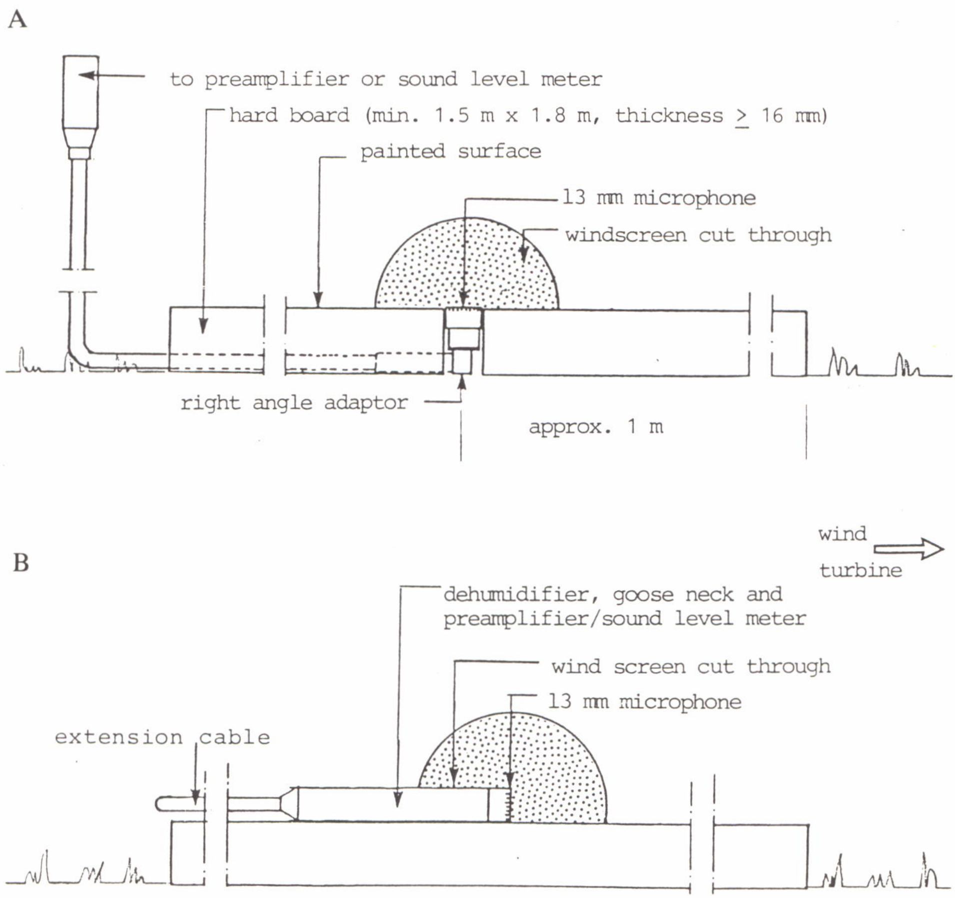



*Figure 2: Examples of microphone systems using a hard chip- or plywood-board.*
*Set-up A: Flush-mounted microphone.*
*Set-up B: "parallel"-mounted microphone.*

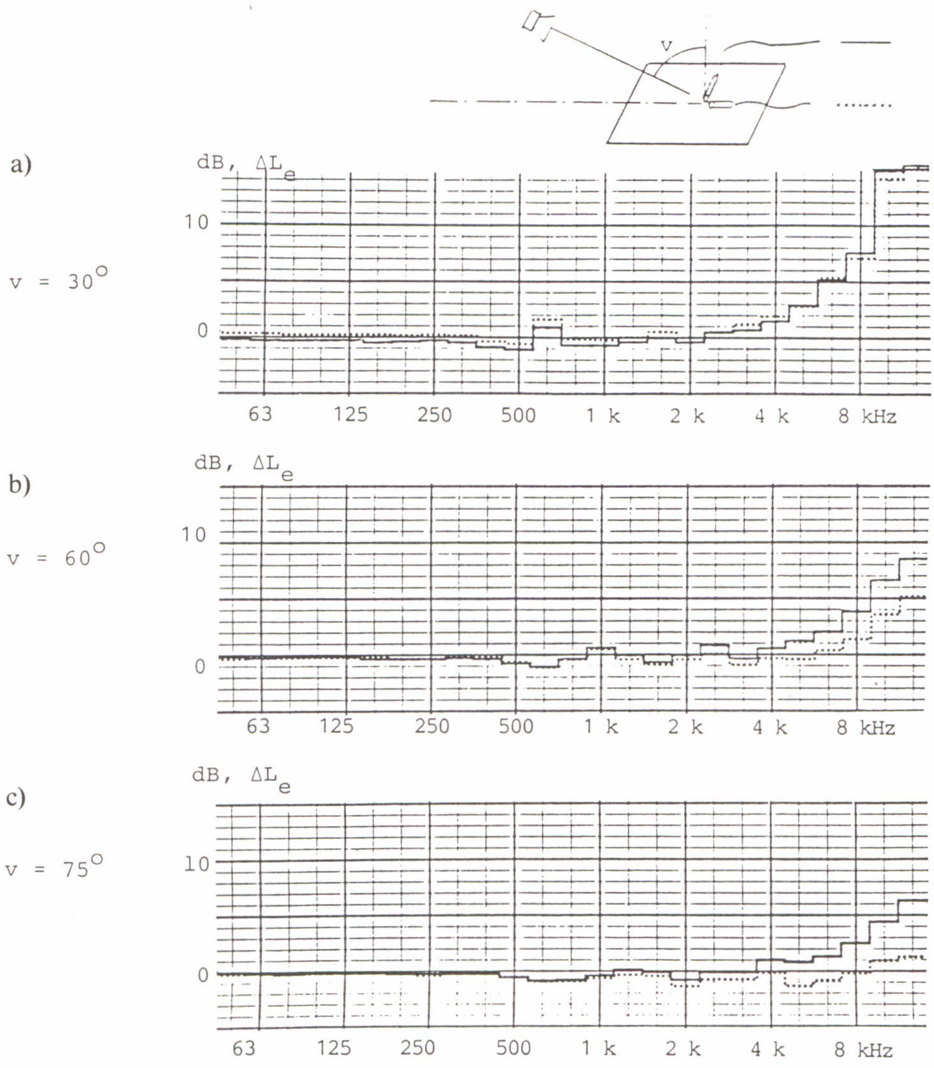



*Figure 3: Under-estimation using microphone set-up B instead of A.*
*Difference ($\Delta L_e$) between ⅓-octave band spectra measured with flush-mounted and "parallel"-mounted microphone.*
*v indicates the angle of sound incidence.*
*____ in the membrane plane and ... microphone pointing towards the sound source.*

# APPENDIX 3.

## PREDICTION OF NOISE LEVELS AROUND A WIND TURBINE

This appendix desribes a method to predict the noise from a wind turbine in its surroundings.

Often it is very dificult to measure the noise from a wind turbine at long distance due to background noise - mostly from the wind acting upon trees and bushes - and to wind-generated microphone noise. In such cases and in a planning situation where the siting of a wind turbine is investigated, it is advantageous to predict the noise.

1. From the sound pressure levels close to the wind turbine the sound power level can be calculated. When the measurements are carried out at longer distances from the tower base than one hub height (preferably between one and two hub heights), the wind turbine can be regarded as a point source.

   The measured sound pressure levels are corrected for the ground effect. In this way the free-field sound pressure levels are obtained. The sound power level is:

   $L_W = L_{p,\,free} + 10\ \lg(4\pi R_i^2)$

   $R_i$ is the distance between measurement point and hub,

   $L_{p,\,free}$ is the average of free-field sound pressure levels at this distance.

   In many cases it is relevant to predict the noise from the wind turbine in the downwind direction only. Such cases exist e.g. when noise limits apply to the maximum noise rather than to the long-term average. In such cases the "downwind" sound power level is calculated on the basis of one or a few sound pressure levels measured in the downwind sector.

   The correction for the ground effect can be made when the ground is totally reflecting (concrete, asphalt, or the like). When the microphone is situated at a finite height above the reflecting ground, the free-field sound pressure level is estimated as:

   $L_{p,\,free} = L_p - 3\ \text{dB}$

   When the microphone is very close to a reflecting surface placed upon the ground (preferably flush-mounted in this surface), the free-field sound pressure level is found with reasonable accuracy as:

   $L_{p,\,free} = L_p - 6\ \text{dB}$

   Estimates of the free-field sound pressure level based on sound pressure levels measured above porous (acoustically soft) ground is subject to a considerable uncertainty and is not recommended.

2. On the basis of the sound power level or the "downwind" sound power level, the sound pressure level in the downwind direction at the distance R from the hub is found as:

   $L_p(R) = L_W - 10\ \lg(2\pi R^2) - \Delta L_a$

   $\Delta L_a$ is the correction for air absorption. It can be calculated as $\Delta L_a = R x \alpha_a$, where $\alpha_a$ is shown for standard atmospheric conditions in Table 1 below.

| 1/1 octave centre frequency, Hz | 63 & 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
|---|---|---|---|---|---|---|---|
| $\alpha_a$, dB/m | 0.000 | 0.001 | 0.002 | 0.004 | 0.007 | 0.017 | 0.056 |

Table 1. Coefficients for sound absorption in the air. Valid for t = 15°C, RH = 70%. Reference made to e.g. ANSI S 1.26 - 1978 "Method for calculation with absorption of sound by the atmosphere".

A limited number of measurements around small and medium-sized wind turbines (P: 50–75 kW, hub height: 22–30 m, wind speeds: 6–10 m/s at 10 m height) have shown that noise levels predicted in this way are in reasonable agreement with measured noise levels (deviations of A-weighted sound pressure levels were generally within ±2 dB). It was also found that serious differences occurred when the prediction was instead based on a more detailed prediction method, taking the effect of the porous ground into consideration e.g. Kragh et al. "Environmental noise from industrial plants. General prediction method". Danish Acoustical Institute, Report No. 32, Lyngby 1982.

# APPENDIX 4.

## MEASUREMENT OF BACKGROUND SOUND

The background sound at a wind turbine site is usually generated in several different ways. Typical examples are aerodynamic sound from the interaction of the wind with buildings and trees, rustle of levels, sound from birds and other animals, sound from human activities, noise from factories, cars and trucks, trains, aircraft etc. Of these different types, the sound generated by the wind is of particular interest as it has a frequency spectrum that is similar to that of the broadband noise generated aerodynamically by a wind turbine. This implies that the noise from a wind turbine can be masked by natural wind sound. Thus, a relevant assessment of the wind sound is of particular interest.

As the background sound is important for the masking of the noise from a wind turbine, it is of utmost importance that the background sound is measured at relevant points, i.e., the same points where the noise from the wind turbine is deemed to be important. In many cases this will lead to measurement points near existing or future houses. It should be observed, however, that the existance of a new house at a site may well change the background sound situation.

It is recommended that the same measurement technique is used as that described in Appendix 2 and Chapter 2 of the main text in order to minimize the wind-induced noise from the microphone. The measurements should be carried out at the two wind speeds described in clause 3.2.1 of the main text. The wind speed should be measured at a point or points relevant for the generation of the background sound. A measurement height of 10 m is recommended.

At each measurement point, the same acoustical quantities should be obtained as at the reference point when the noise emission from the wind turbine is determined, see clause 3.2.2. As there still are many unclear points in connection with the assessment, and especially the masking effect, of the background sound it is recommended that tape recordings be made and saved for future evaluations.

It is strongly recommended that photographs of the surroundings of the measurement points are included in the report.

# APPENDIX 5.

## A COMMENT ABOUT TURBINES WITH A VARIABLE ROTATIONAL SPEED

The aerodynamically generated noise is strongly dependent on the rotational speed of a wind turbine. The sound level in dB(A) generally varies as 50 lg(RPM) where RPM is the number of revolutions per minute.

Measurements should be made at a wind speed close to where the turbine reaches its maximum rotational speed.

For turbines with fast response of the rotational speed to variations of the wind speed through the rotor care must be taken if attempts are made to correlate the noise with a wind speed not measured close to the rotor.

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