Noise Immission from Wind Turbines

Final Report of Project JOR3-CT95-0065

J. Kragh, DELTA
D. Theofiloyiannakos, CRES
H. Klug, T. Osten, DEWI
B. Andersen, dk-TEKNIK
N. van der Borg, ECN
S. Ljunggren, O. Fégeant, KTH
R. J. Whitson, NEL
J. Bass, RES
D. Englich, C. Eichenlaub, R. Weber, Uni-Ol

Research funded in part by

THE EUROPEAN COMMISSION
in the framework of the
Non Nuclear Energy Programme
Joule III

Partners

Co-ordinator: J. Kragh, DELTA (from 1st February, 1997)
J. Jakobsen, DELTA (until 31st January, 1997)
Danish Electronics, Light & Acoustics
Building 356, Akademivej, DK-2800 Lyngby, Denmark

Partners: B. Andersen, dk-TEKNIK ENERGY AND ENVIRONMENT
Gladsaxe Møllevej 15, DK-2860 Søborg, Denmark

D. Theofiloyiannakos, CRES
Centre for Renewable Energy Sources
19th km Marathonas Avenue, GR-190 09 Pikermi, Greece

H. Klug, T. Osten, DEWI
German Wind Energy Institute
Ebertstrasse 96, D-26382 Wilhelmshaven, Germany

N. van der Borg, ECN
Netherlands Energy Research Foundation
P.O. Box 1, NL-1755 ZG Petten, The Netherlands

S. Ljunggren, O. Fégeant, KTH
Royal Institute of Technology
S-100 44 Stockholm, Sweden

A. Mackinnon, R. J. Whitson, NEL
National Engineering Laboratory
Reynolds Building, Reynolds Avenue, East Kilbride
Glasgow, UK-G75 OQE, United Kingdom

J. Bass, RES
Renewable Energy Systems Ltd
11, Elmbank Street, Glasgow G2 4PB, United Kingdom

D. Englich, C. Eichenlaub, R. Weber, Uni-Ol
Carl von Ossietzky University
P.O. Box 2530, D-26 111 Oldenburg, Germany

Contents

1. Introduction

The main purpose of the project has been to improve the reliability of statements with regard to wind turbine noise levels whether determined by direct measurement or by calculation.

When planning wind turbines, the following aspects are of considerable importance for environmental noise protection:

- The determination of noise emission values (sound power level, tonality) by means of measurement methods with minimum uncertainty
- The knowledge of noise propagation under different meteorological conditions in order to be able to predict the noise immission at dwellings in the neighbourhood of wind turbines
- The measurement of noise immission in the environment of wind turbines applying improved measurement methods for windy conditions
- The assessment of possible tonal noise due to the machinery components of wind turbines (e.g. from the gear box)

The above-mentioned aspects have been tasks of the project NIWT in broad parts.

Responsibility for parts of the project has been allocated at various partners:

- Development of immission measurement method: KTH
- Tonal assessment: NEL
- Preparation of measurement and analysis of noise immission / propagation: DELTA
- Co-ordination of Round Robin Test: DEWI
- Validation of noise propagation model: DELTA
- Evaluation of uncertainty on emission measurements: DELTA
- Acceptability of wind turbine noise: Uni-Ol

2. Objectives

The project has dealt with practical ways to reduce the influence of background noise caused by wind acting on the measuring microphone.

The uncertainty of measured noise emission (source strength) has been investigated. The main activity was a Round Robin Test involving measurements by five laboratories at the same wind turbine. Each laboratory brought its own instrumentation and performed the measurements and analyses according to their interpretation of [1].

The tonality of wind turbine noise is an essential component of the noise impact on the environment. In the present project the uncertainty in the newest existing methods for assessing tonality was investigated.

The project included noise propagation measurements in different weather conditions around wind turbines situated in different types of terrain. The results were used to validate a noise propagation model developed in the project.

Finally, the project also included a study with listeners evaluating recordings of wind turbine noise. The results are intended as guidance for wind turbine manufacturers in identifying the aspects of wind turbine noise most important to annoyance.

3. Technical Description

3.1 Noise Immission Measurement Method

Wind turbine noise propagation measurements carried out in the present project have given valuable experience. The results aimed at were obtained, and the methods developed for improving the signal-to-noise ratio in outdoor measurements under strong wind are now included in the IEA document [2].

Results obtained in the present project indicate that the methods for assessing tonality described in the IEA documents [1], [2], and the IEC draft standard [3] need improvement.

3.1.1 Reduction of Wind Induced Microphone Noise

Wind induced microphone noise is a major problem in wind turbine noise measurement during strong wind. Four techniques for reducing this so-called pseudo noise were tested in the project.

- *Two microphone cross correlation.* Noise signals from two identical microphones positioned some distance apart were analysed applying correlation technique to suppress wind induced noise components, which are uncorrelated in the two signals. [4].

- *Mounting the microphone on a vertical reflecting board.* The board reduces wind velocity at the microphone, screens the noise from any source behind the board, and causes pressure doubling (+6 dB) for sources in front of the board [5], [6], [7].

- *Directional microphone with supplementary wind shield.* A directional microphone reduces noise from directions other than that of its axis. Wind noise sensitivity of the directional microphone was reduced by mounting a supplementary wind shield [8].

- *Large secondary wind screen.* An extra wind screen used simultaneously with the normal wind screen reduces wind noise. The attenuation of the acoustic signal when transmitted through the secondary wind screen was measured in an anechoic room [9], and the wind induced noise was measured in the field [10], [9], [11].

The reduction of wind-induced noise turned out to be more or less the same no matter which of the methods is used, but from a practical point of view their applicability varies. It was decided to use a special large secondary wind screen for the noise propagation measurements carried out in the project.

3.1.2 Tonal Assessment

Tonal assessment is important in immission measurement and emission measurement of wind turbine noise. Tonality is the number of decibels the level of (a) tone(s) is higher than the level of the remainder of the noise in a critical band around the tone(s).

NEL received tape recordings from five partners made during the Round Robin measurements, and NEL and RES both analysed the tapes [12], [13]. In addition, DELTA made a tape with samples of tonal noise [14] for partners to analyse [15], [16]. NEL included results for one of these samples in their report [12].

All analyses were made according to the IEA procedure 3rd edition 1994 [1]. Up to 10 dB variation was found between partners' assessment of the tonality, perhaps due to sections of the IEA-procedure being open to interpretation. Thus there is a need for improved or more closely defined methods for assessing wind turbine noise tonality.

3.2 Sound Propagation Model

3.2.1 Measurement of Wind Turbine Noise Propagation

Seven partners measured wind turbine noise propagation at selected sites in their country, and a large number of new data were collected during the project[1)]. Measurements were made simultaneously on a ground board near the wind turbine to monitor the source output, and in immission points further away to determine noise attenuation during propagation.

3.2.2 Validation of Propagation Model

DELTA compared measurement results with results of calculation [17]. The new propagation model *WiTuProp* fits well with measurement results.

---

1) These data have been at the disposal of another project, JOR3-CT96-0098, since October 1997.

WiTuProp is based on the so-called "heuristic model" concept [18], adapted and developed by DELTA [17]. Screening is taken into account according to Maekawa, modified for curved rays as described in [19].

DELTA made calculations by this model and according to the Parabolic Equation (PE) approach [20] while Uni-Ol made calculations by means of a Fast Field Programme (FFP) and a Ray Tracing Programme (RTP), [17], [21].

The results of these calculations were compared in [17] with DELTA's "old" measurement results [22]. There was reasonable agreement for downwind and crosswind, although large deviation was found in low microphone positions at 400 m distance. Upwind calculations were in acceptable agreement with measurement results except at 400 m distance where the microphone in some cases was in the shadow zone.

The data collected in the present project are summarised in [17]. The agreement between measurement results and *WiTuProp* is good, especially taking into account that propagation distances up to 600 m are involved.

The behaviour of WiTuProp was looked into by calculations made by Uni-Ol and DELTA for specified weather, ground, and geometrical conditions. The weather conditions were decided upon by DEWI and Uni-Ol as typical for wind turbine noise propagation during night (stable conditions) and during day (unstable conditions), [21]. The ground was assumed grass-covered, and a typical source frequency spectrum was assumed [22].

Concerning the ground effect[2)] on the A-weighted overall noise levels from wind turbines the following was concluded [23]:

- *Downwind* the ground effect is between +1 dB and +2 dB independent of the source–receiver distance.
- *Crosswind* the ground effect is between +1 dB and +2 dB for all source–receiver distances up to 1000 m when the source height is 80 m, and up to 600 m or 700 m when the source height is 40 m.
- *Upwind* the ground effect is between +1 dB and +2 dB for all source–receiver distances up to 700 m when the source height is 80 m, and up to 400 m when the source height is 40 m. At larger distances a transition takes place over a range of distance to a ground effect of –15 dB or so in the shadow zone.
- *Night- and daytime noise levels*: there is no significant difference between A-weighted noise levels calculated for stable and unstable conditions.

---

2) The ground effect is the change in noise level caused by the presence of the ground surface. It is often called "the sound pressure level relatively to the free-field sound presure level".

3.2.3 Programming the Sound Propagation Model

The program *WiTuProp* is written in Turbo Pascal 6.0 (DOS). Further information is given in [17], including the program listing of the prediction algorithms.

3.3 Round Robin Test of Noise Emission Measurement

The uncertainty of the sound power level, due to individual differences between wind turbines of a given make and model, has been found to be in the order of 1 dB, expressed as one standard deviation, for the measured apparent sound power level, while repeatability uncertainty is 0.3 dB [24].

In the present project five partners measured the noise emission of the same 500 kW wind turbine in a flat terrain, during two sessions. DEWI co-ordinated the measurements, and compiled the results [25].

Partners' results are given in [26]-[30]. They all measured sound power level, wind speed dependence, and tonality. Measurements were made simultaneously[3)], according to the procedures of [1].

- The maximum differences between measured *apparent sound power levels* were of the order of 0.5 dB, with 0.2 dB or 0.3 dB standard deviation of differences[4)].
- The *wind speed dependence* deviated less than 0.2 dB per m/s with a standard deviation of differences smaller than 0.1 dB per m/s[3)].
- The measured *tonality* deviated by up to 10 dB, with a 3 or 4 dB standard deviation of differences, depending on operation conditions (stationary or non-stationary).

Most important for the deviation in measured tonality may be variation in partners' interpretation of the method in [1], but also the ground board may have had influence.

3.4 Uncertainty of Noise Emission Measurement

Four partners investigated uncertainty components in wind turbine noise emission with DELTA responsible for summarising the findings. The investigations were designed to complement the results of a previous project [24].

3.4.1 Ground Board

NEL made a direct side-by-side comparison of wind turbine noise emission measurement results using a 1 m round and a 1.5 m × 1.8 m rectangular board, placed on an even grass-field [31]. Total A-weighted levels showed deviations of only 0.2 dB, while

---

3) In two series, with DEWI participating in both, see for example [25].

4) The number depends on whether directly measured or calculated wind speeds are used, see [25].

individual 1/3-octave band levels differed by 0.5∀1 dB in the frequency range from 80 Hz to 4 kHz.

Supplementary comparisons were made of the results obtained during Round Robin measurements of noise emission. Two round boards were used as well as a rectangular board. The edges of one round board were covered by soil. The measurement results differed more than expected, and perhaps some of these differences were due to other reasons than differences in board size and shape.

With varying size and shape of the ground board placed on an even ground 0.1 dB or 0.2 dB deviations in overall A-weighted levels can be expected, while up to 1 dB deviation in 1/3-octave band levels may occur. Until more detailed investigation of board effects can be carried out, users should consider where practicable either “burying” the board into the ground or covering the board edges by soil.

3.4.2 Turbulence

According to theory the aerodynamic noise from a wind turbine depends on the turbulence in the air incident on the rotor. At a site with undulating ground the air in-flow on the rotor is more turbulent than at a flat site, and thus the sound power level of a given wind turbine might be site dependent.

RES re-analysed data from measurements carried out earlier at seven different wind turbine models [32]. The connection between sound power level and wind speed was compared with the correlation obtained when the standard deviation of the wind speed fluctuations was included in regression analyses. No improvement was found by introducing fluctuation measures in the analyses, indicating the effect of in-flow turbulence on the sound power level of wind turbines to be insignificant.

3.4.3 Measurement Distance

DEWI has investigated the influence on the measured wind turbine noise emission of varying the measurement distance [33] within the tolerances R_0 ∀ 20% prescribed in the IEA-document [1] or draft IEC standard [3].

DEWI measured at a 500 kW and a 600 kW wind turbine, at a distance R_0, R_0+20%, and R_0 –20%, respectively. The maximum deviation between the total A-weighted sound power levels based on measurements at distances R_0 and R_0 ∀20% were 0.1 dB as was the standard deviation of differences between results.

dk-TEKNIK measured at a 600 kW wind turbine [34], at distances R_0 ∀20%, and found differences of less than 0.3 dB between results of measurements.

3.4.4 Position for Wind Speed Measurement

The wind speed is a primary parameter in wind turbine noise measurement because noise emission increases with increasing wind speed, and therefore a reference wind speed has to be defined for which the noise emission (sound power level) shall be specified.

dk-TEKNIK investigated the uncertainty introduced in measurement of wind turbine noise emission by using different wind speed sensor positions [34] within the tolerances given in the draft IEC standard [3] or IEA-document [2]. They measured the noise from a 600 kW wind turbine, using anemometers placed at four positions. At the same time they determined the wind speed based on the wind turbine power curve.

The standard deviation of the measured total A-weighted sound power level was 0.5 dB, indicating an uncertainty component in that order of magnitude, for a 35 m high wind turbine situated in flat farmland.

Measurements carried out by DEWI at a wind turbine in an undulating terrain gave a 3 dB difference between the sound power levels based on the directly measured wind speed and on the calculated wind speed, respectively, based on the power curve. Measurements at a similar wind turbine in a flat terrain later confirmed the sound power level based on the calculated wind speed to be correct [35].

3.5 Acceptability of Wind Turbines

The investigations of wind turbine noise acceptability have been carried out by Uni-Ol [36], while co-ordination during the project period with similar Swedish research has been ensured by KTH.

Tape recordings of the noise were made by DELTA, DEWI, and Uni-Ol at different wind turbines, especially for investigating wind turbine noise acceptability. Both stereo recordings with an artificial head and monaural recordings on a “ground board” were made.

These recordings were presented to 29 test persons in the laboratory at Uni-Ol. Each person compared the noises and was subsequently interviewed to identify the person’s criteria for deciding which noise was more unpleasant. Variation in judgement behaviour was identified, resulting in a division of test persons into groups applying different criteria.

Uni-Ol made new tape recordings, using an artificial head, of the noise at 35 – 80 m distance from 10 different wind turbines. These noises were presented to 17 persons in paired comparisons of unpleasantness, and the noise signals were also analysed by means of a binaural analysis system to determine a number of psycho-acoustic parameters.

The judgements made by the test persons were used to rank the noises and to perform a hierarchical cluster and factor analysis. Many test persons judged the unpleasantness in the same way, and their judgements fit with rankings of the noises computed for the parameters “tonality”[5)] and “fluctuation strength”.

The Swedish project is still in progress. In experiments carried out at the University of Gothenburg five different wind turbine noises were presented to test persons at a level of L_{Aeq} = 40 dB [37]. The test persons were able to differentiate between the noises presented, with regard to “annoyance” and “duration of awareness” and psycho-acoustic descriptors such as “tonal”.

4. Exploitation

The project has led to more accurate methods for assessing environmental noise impact of wind turbines.

The noise propagation model *WiTuProp* developed in the project allows more accurate calculations than has been possible until now. This method is available to partners and other interested parties as a PC program.

The information collected on uncertainty components of measured noise emission is an important contribution to a future system for declaring the noise from wind turbines, to be worked out by CENELEC BTTF Working Group 4.

Project partners have immediately used the knowledge obtained in their daily activity.

Measured noise propagation data have been at the disposal of project JOR3-CT96-0098, also dealing with wind turbine noise propagation since October 1997.

DELTA has made calculations by means of *WiTuProp* for application in another Joule project (“Development of a Wind Farm Noise Propagation, Prediction Model”, JOR3-CT95-0051). The situations to be predicted for were specified by RES being at the same time a partner of both projects.

Partners are involved in international standardisation and many participate in national working groups dealing with planning and assessment of wind turbine noise. This ensures that project results will be implemented immediately. The improved measurement methods have been incorporated in [2], and details have been presented at EWEC97, [6], [11], and published in Applied Acoustics [7]. The exchange of data, views and experience that has taken place between partners is considered extremely valuable.

---

5) This parameter is *not* the same as the tonality mentioned in Sections 3.1.2 and 3.4.3.

5. Conclusions

The main results were:

- Essential contributions have been made to an improved noise immission measurement method published as IEA recommendations [2]. In particular, methods have been investigated for reducing wind induced microphone noise. A special secondary wind screen has been designed and recommended for practical measurements and it has been shown that a vertical board can be used to the improve signal-to-noise ratio.

- A new noise propagation model has been developed, validated and programmed, based on data from measurement and calculation of wind turbine noise propagation carried out within the present and an earlier project. Noise attenuation in 1/3-octave bands is calculated. For most practical calculations the ground effect on the overall A-weighted noise level of a wind turbine can be assumed to be between +1 and +2 dB, as an approximation. Calculated and measured attenuation of total A-weighted noise levels are estimated to agree within 1 or 2 dB in these cases, while larger inaccuracy should be expected in other cases, especially in shadow zones.

- Round Robin testing showed that sound power levels determined simultaneously by different partners were within approximately 0.5 dB, while measured tonality differed by up to 10 dB, primarily due to variation in partners' interpretation of the method. The latter implies that the tonality measurement method should be further developed and tested once procedures are defined in more detail.

- The reproducibility of the measured overall A-weighted sound power level for a given make and model of wind turbine is in the order of 1.5 dB, expressed as one standard deviation, when the wind turbine is situated in flat terrain. In undulating terrain the measured sound power level may depend on how the wind speed is measured. Measuring wind speed 10 m above the ground can lead to unacceptable uncertainty in noise emission of tall wind turbines, and declaration of wind turbine noise should be based on wind speed calculated by means of the power curve.

- Varying size and shape of ground boards led to less than 0.2 dB differences in measured sound power level, while variation in incident air turbulence and varying measurement distance had no measurable effect. Varying the wind speed sensor positions implied 0.5 dB deviations in sound power level of wind turbines in flat terrain.

- A laboratory technique has been developed for assessing subjective unpleasantness of wind turbine noise. Noise tonality and noise fluctuation strength seemed to be the psycho-acoustic signal parameters best correlated with unpleasantness.

6. References

[1] S. Ljunggren (ed.), “Recommended Practices for Wind Turbine Testing. 4. Acoustics. Measurement of Noise Emission from Wind Turbines.” 3. Edition 1994. Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems.

[2] S. Ljunggren (ed.), “Recommended Practices for Wind Turbine Testing. 10. Measurement of Noise Immission from Wind Turbines at Noise Receptor Locations.” 1. Edition 1997. Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems.

[3] Doc. 88/67/FDIS - IEC 1400-11, “Wind Turbine Generator Systems - Part 11: Acoustic Noise Measurement Techniques”.

[4] “Measurement of Wind Turbine Noise Immission with a Two-Microphone Technique”, Netherlands Energy Research Foundation, Report ECN C—96-074, Petten 1996.

[5] “Immission Measurement Technique for Wind Turbine Noise: Pseudo-Noise and Sound Diffraction at the Measurement Board”, Royal Institute of Technology, Division of Building Technology, Working Report 1997:7, Stockholm 1997.

[6] O. Fégeant, “Measurements of noise immission from wind turbines at receptor locations: Use of a vertical microphone board to improve the signal-to-noise ratio”, Proceedings EWEC97, Dublin 1997.

[7] O. Fégeant, “On the use of a vertical microphone board to improve low signal-to-noise ration during outdoor measurements”. Applied Acoustics, Vol. 53, No. 4, p. 291-312, 1998.

[8] “Noise Immission Measurements in the Vicinity of Wind Turbines. Test of a Directional Microphone”, Deutsches Windenergie-Institut, DEWI-Report AS 961204, Wilhelmshaven 1996.

[9] “Investigations of Wind Screens. Insertion Loss and Attenuation of Wind Noise”, DELTA Acoustics & Vibration, Report AV 50/97, Lyngby 1997.

[10] “Investigation of the Reduction of the Wind Induced Microphone Noise by Use of Supplementary Wind Screens”, Centre for Renewable Energy Sources, Report CRES.WE.NIWT.05, Pikermi 1998.

[11] D. Theofiloyiannakos et al., “Investigation of the Reduction of the Wind-Induced Microphone Noise by the Use of Supplementary Wind Screens”, Proceedings EWEC97, Dublin 1997.

[12] “Comparison of Partners’ Results for IEA Round Robin Tonality Analysis”, National Engineering Laboratory, NEL Report No. 308/96, Glasgow 1997.

[13] “Round Robin Assessment of Tonality for the NIWT Project”, Renewable Energy Systems Ltd, Report No. 062/RES/2005, Glasgow 1997.

[14] “Round Robin Tonal Analysis. Note 2, JOR3-CT95-0065”, DELTA Acoustics & Vibration, Technical Note AV 71/97, Lyngby 1997.

[15] “Evaluation of the Round Robin Tape of Tonal Assessment”, Deutsches Windenergie-Institut, DEWI-Report AS 970407, Wilhelmshaven 1997.

[16] “Tonality Analysis of the DELTA-Round Robin Tape”, Netherlands Energy Research Foundation, ECN DE Memo 96-58, Petten 1996.

[17] “Wind Turbine Noise Propagation Model”, DELTA Acoustics & Vibration, Report AV 1119/98, Lyngby 1998.

[18] A. L’Espérance et al., “Heuristic Model for Sound Propagation Based on an Extension of the Geometrical Ray Theory in the Case of a Linear Sound Speed Profile”, Applied Acoustics Vol. 37, p. 111-139, 1992.

[19] “Environmental Noise from Industrial Plants. General Prediction Method.” Danish Acoustical Institute, Report No. 32, Lyngby 1982.

[20] M. Galindo, “The Parabolic Equation Method for Outdoor Sound Propagation”, Ph. D. Thesis, Report No. 68, Department of Acoustic Technology, Technical University of Denmark, Lyngby 1996.

[21] “Validation of Propagation Models”, Carl von Ossietzky University, Oldenburg 1997.

[22] “Propagation of Wind Turbine Noise. Outline of a Prediction Method”, DELTA Acoustics & Vibration, Report AV 320/95, Lyngby 1995.

[23] “Behaviour of Wind Turbine Noise Propagation Model, WiTuProp”, DELTA Acoustics & Vibration, Technical Note AV 1146/98, Lyngby 1998.

[24] “Noise from Wind Turbines. Final report of Project JOU2-CT92-0124”, Netherlands Energy Research Foundation, Report ECN C—95-036, Petten 1995.

[25] "Round Robin Test of Acoustic Noise Emission Measurement on a Wind Turbine", Deutsches Windenergie-Institut, DEWI-Report AS 971010, Wilhelmshaven 1997.

[26] "Acoustic Noise Measurements on a Wind Turbine performed in the Frame of the NIWT-Round Robin Test", Centre for Renewable Energy Sources, Report CRES.WE.NIWT.03, Pikermi 1998.

[27] "Round Robin Measurements of Noise Emission on a Tacke TW 500/37 Wind Turbine", Deutsches Windenergie-Institut, DEWI-Report AS 970206, Wilhelmshaven 1997.

[28] "Noise Emission from Tacke TW 500/37", dk-TEKNIK Technical Note No. 10907.1, Søborg 1997.

[29] "Acoustic Noise Measurements on a Wind Turbine performed in the Frame of the NIWT Round Robin", Netherlands Energy Research Foundation Report ECN C—96-086, Petten 1996.

[30] "Result of NEL Round Robin Measurements made at DEWI, Wilhelmshaven on 22 April 1996", National Engineering Laboratory, NEL Report No. 306/96, Glasgow 1997.

[31] "Comparison of Noise Emission Data for Different Types of Ground-Reflecting Board", National Engineering Laboratory, NEL Report No. 307/ 96, Glasgow 1997.

[32] "The Effects of Turbulence Intensity & Roughness Length on Measurements of a Wind Turbine's Sound Power Level", RES Report No. 062/RES/2006, Glasgow 1997.

[33] "Noise Immission Measurements on Wind Turbines at Measurement Distances R0∀20%", Deutsches Windenergie-Institut, DEWI-Report AS 971012, Wilhelmshaven 1997.

[34] "Uncertainty on Noise Emission Results", dk-TEKNIK Technical Note No. 10907.2, Søborg 1997.

[35] T. Osten, personal communication, March 1998.

[36] "Acceptability of Wind Turbine Noise", Carl von Ossietzky University, Oldenburg 1997.

[37] K. Persson Waye et al., "Psycho-Acoustic Characters of Relevance for Annoyance and Perception of Wind Turbine Noise", Proceedings Internoise 97, vol. III, p. 1187-1190, Budapest 1997