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Teknisk Notat

Ny Viden

2015-1

MILJØSTYRELSENS
REFERENCELABORATORIUM
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DELTA, 17. september 2015

Jens E. Laursen

Indholdsfortegnelse

1. Baggrund og formål

Miljøstyrelsen har ønsket, at en del af Referencelaboratoriets aktiviteter i 2015 skulle være at formidle ny viden til Miljøstyrelsen og andre interesserede. Referencelaboratoriet har gennemgået tidsskrifter og samlet en oversigt over årets kongresser for at identificere ny viden af betydning for måling og administration af ekstern støj. Søgningen i tidsskrifter er afsluttet i juni 2015.

Indholdsfortegnelser for de valgte tidsskrifter findes på de respektive hjemmesider på Internettet. Links til disse hjemmesider er angivet i Bilag 1.

Dette nummer af Ny Viden indeholder især artikler om vindmøllestøj og vejtrafikstøj. I Bilag 2 er vedlagt relevante abstracts fra vindmøllekonferencen i Melbourne 2014.

2. Afgrænsning

Valg af emner og vægtning af stoffet er rettet mod Miljøstyrelsen.

3. Tidsskrifter

3.1 Journal of the Acoustical Society of America (JASA)

Årgang 2014: Vol. 136, No. 5 - 6 (november - december)

Årgang 2015: Vol. 137, No. 1 - 6 (januar - juni)

Et link til dette tidsskrift findes i Bilag 1. Der er fundet følgende artikler:

Experimental characterization of vertical-axis wind turbine noise

Vol. 137, No.1, C. E. Pearson and W. R. Graham

Artiklen er ikke fundet umiddelbart relevant.

The subjective effect of low frequency content in road traffic noise

Vol. 137, No.1, pp.189, Antonio J. Torija and Ian H. Flindell

Forfatterne har i tidligere forsøg (JASA Vol.135, no.1-4 (2014)) observeret, at indholdet af den lavfrekvente del af trafikstøjen fra hovedveje i byer syntes at have mindre betydning for støjgenen end, hvad der kan udledes af objektive støjparametre.

Nærværende artikel beskriver et laboratorieforsøg, hvor 33 forsøgspersoner lyttede til optagelser af vejtrafikstøj optaget 3,5 m fra en vej med biler med lav hastighed. Forsøgspersonerne

skulle bedømme loudness og genevirkning. De originale lydoptagelser var filtreret for at fremhæve LF-området (20-25 Hz) og sænke midt- og højfrekvensområdet (350 – 20.000 Hz) i små spring.

I nærværende artikel beskrives en mere detaljeret undersøgelse, som havde til formål at
(1) identificere forskellen i lydeksempler for udendørs oplevet trafikstøj, hvor lavfrekvensindholdet (LF) i støjen bliver subjektivt mere dominerende over midt- og højfrekvensområdet (MHF)
(2) at undersøge forholdet mellem loudness og geneoplevelse under forhold, hvor lavfrekvensindholdet er relativt mere dominerende, som fx indendørs, hvor midt- og højfrekvensområdet er reduceret.

Resultaterne fra Test 1 med udendørs lydoptagelser antydede, at i de lydeksempler, hvor niveauet af lavfrekvensområdet var mere end 30 dB over niveauet af midt- og højfrekvensområdet, oplevede lytterne at trinvise ændringer af niveauet i lavfrekvensområdet havde en lige så stor subjektiv betydning for geneoplevelsen som tilsvarende trinvise ændringer i midt- og højfrekvensområdet.

Resultaterne fra Test 2, som omhandlede lydeksempler med trafikstøj modificeret til et indendørsspektrum, viste for både gene- og loudnessoplevelsen, at ændringer i forholdet mellem LF- og MHF-niveauet kun gav mindre ændringer end hvad der kunne udledes af variationerne af objektive støjparametre L_{Aeq} og L_{Ceq}.

Artiklen konkluderer, at den almindelige kritik af A-frekvensvægtningen med hypotesen om, at A-filteret har en overdreven frekvensvægtning nedadtil, kan være relativt ubegrundet, når det drejer sig om trafikstøj.

Forfatterne påpeger, at undersøgelsens resultater kun er baseret på lytteforsøg i et laboratorium, og derfor ikke indregner effekter der optræder i felten, hvor fænomener som raslen og vibrationer kan forekomme samtidig med luftlyden. Andre undersøgelser har vist, at forekomsten af raslen og vibrationer fra trafikstøjen i boliger kan bidrage betragteligt til beboernes geneoplevelse.

Effects of age and hearing loss on the intelligibility of interrupted speech

Vol. 137, No.2, pp. 745, Valeriy Shafiro, Stanley Sheft, Robert Risley and Brian Gygi

Artiklen er ikke fundet umiddelbart relevant.

3.2 Applied Acoustics

Årgang 2015: Vol. 89-98 (marts-nov)

Et link til dette tidsskrift findes i Bilag 1. Der er fundet følgende artikler:

Meteorological effects on wind turbine sound propagation

Vol 89, pp. 34-41, Olof Öhlund, Conny Larsson

Forfatterne har over en 2-årig periode foretaget målinger af støj-, temperatur- og vindforhold ved to vindmølleparker i Sverige. Undersøgelsen er tidligere beskrevet mht. indholdet af Amplitude Modulation: *Amplitude modulation of sound from wind turbines under various meteorological conditions,* JASA Vol. 135, No.1, p. 67 (resumé i Ny Viden 2014).

I nærværende artikel har forfatterne benyttet måleresultaterne til at foretage en sammenligning med følgende 2 modeller til beregning af lydudbredelse: ISO9613-2 og SEPA (en støjmodel fra den svenske miljøstyrelse, Naturvårdsverket). Kun data med medvind (± 45°) fra den mest dominerende vindmølle og målinger uden snedække er medtaget.

Det ene målested - Ryningsnäs - ligger i et område med lav skovbevoksning, og der står her 2 vindmøller med navhøjde 80 m og 100 m, hver med effekten 2,5 MW. Det andet målested - Dragaliden - ligger i Nordsverige i et mere bakket område med både skovbevoksning og sumpområder, hvor der findes 12 vindmøller med navhøjden 108 m og 138 m, hver med effekten 2 MW. Begge målesteder har meget lavt baggrundsstøjniveau, og der er henholdsvis 1 km og 1,7 km til nærmeste vej. Afstanden til målemikrofonen fra den nærmeste vindmølle var ca. 500 m henholdsvis 1 km i Ryningsnäs og i Dragaliden.

Både ISO9613-2 og SEPA støjmodel giver god overensstemmelse med måleresultatet for Ryningsnäs, som lå tættest til målepunkterne (ca. 500 m), bortset fra de mellemhøje støjniveauer, som var underestimereret med ca. 3 dB med SEPA og 4 dB med ISO9613-2.

Ved Dragaliden, som lå ca. 1 km fra mikrofonpositionen, var de højeste støjniveauer underestimeret med ca. 5 dB med SEPA og 7 dB med ISO9613-2 i forhold til målingerne.

Det vises, at resultaterne opnået med ISO-metoden kan forbedres ved i modellen at benytte akustisk hårdt terræn, selv om terrænet er akustisk porøst. Overensstemmelsen med målingerne gælder da især de højeste niveauer, mens lavere niveauer overestimeres en smule.

3.3 Journal of Low-Frequency Noise, Vibration and Active Control

Årgang 2014: Vol. 33, No. 4 (december)

Årgang 2015: Vol. 34, No. 1 (marts)

Et link til dette tidsskrift findes i Bilag 1. Der er ikke fundet relevante artikler.

3.4 Noise Control Engineering Journal

Årgang 2014: Volume 62, No.5-6 (september - november)

Årgang 2015: Volume 63, No.1-3 (januar - maj)

Et link til dette tidsskrift findes i Bilag 1. Der er fundet følgende artikler:

Perception of low frequency components in wind turbine noise

Vol. 62, No.5, pp. 295-305, Yokoyama, Sakae; Sakamoto, Shinichi; Tachibana, Hideki

Forfatterne har i en række laboratorieforsøg undersøgt hørbarheden af LF-komponenter i vindmøllestøj oplevet udendørs. Tre lytteforsøg blev udført i et specielt kammer med et højttalersystem, der kunne gengive lave frekvenser ned i infralydområdet (4-125 Hz).

I det 1. forsøg blev hørbarheden af lavfrekvente komponenter i 3 lydoptagelser af vindmøllestøj målt udendørs samt 3 kunstigt fremstillede lyde, som spektralt set lignede vindmøllestøj. De 6 lydeksempler blev herefter modificeret ved at ændre støjens spektrale indhold med lavpasfiltrering med afskæringsfrekvenser fra 10 til 125 Hz.

I det 2. forsøg blev høretærsklerne for lyde med et dominerende lavfrekvensindhold testet ved at ændre bredden af frekvensbåndet i syv trin for at undersøge 1/3-oktav-båndene tæt ved høretærsklen.

I det 3. forsøg blev loudness-forsøg udført med kunstig vindmøllestøj, hvor frekvenskarakteristikken for testlyden blev ændret ved at anvende højpasfiltrering med ni forskellige cut-off frekvenser fra 16 Hz til 1 kHz.

Forsøg 1 viser, at for den generelle vindmøllestøj, der findes udendørs i immissionsområder omkring vindmølleparker, er de lavfrekvente komponenter i infralydområdet, og ved lave frekvenser i det hørbare frekvensområde, næppe hørbare/mærkbare. Dette blev bekræftet af resultatet i forsøg 3, som viste at de lavfrekvente komponenter næsten ikke bidrog til loudness-oplevelsen.

Det bekræftes, at høretærskler for lyde, der indeholder dominerende komponenter ved lave frekvenser, godt kan bedømmes i forhold til de høretærskelværdier, der er angivet i DIN 45680 og i de hollandske NSG-retningslinjer samt kriteriekurven foreslået af Moorhouse et al. Høretærskelkurven for rene toner i det hørbare frekvensområde specificeret i ISO389-7 kan også benyttes som reference til vurdering af hørbarheden af lavfrekvente lyde, hvor der benyttes 1/3-oktav-bånd analyse, men reference-kurven skal da sænkes med ca. 5 dB.

I forsøg 2 blev det konstateret, at høretærsklen for de 7 lydeksempler, der indeholder dominerende bestanddele ved lave frekvenser, er ca. L_{Aeq} = 20 dB(A) uafhængigt af afskæringsfrekvensen for lavpasfiltret. Høretærsklen for det C-vægtede lydtrykniveau falder fra 70 dB(C) til 40 dB(C), for de 7 lydfiler hvor lavpasfiler-afskæringsfrekvensen er henholdsvis 20, 25, 31.5, 40, 50, 63 og 80 Hz.

Forsøg 3 viser, at for en bred vifte af lyde, som indeholder forskellige lavfrekvenskomponenter, er det A-vægtede lydtrykniveau pålideligt til loudnessvurderinger.

Local impact assessment of urban traffic noise

Vol. 62, No.6, pp. 449-466(18)

Authors: Salomons, Erik M.; Janssen, Sabine A.; Verhagen, Henk L.M.

Forfatterne har undersøgt forholdet mellem trafikstøj, støjgener og søvnforstyrrelser i forbindelse med konsekvensundersøgelser af støjdæmpning af et lille byområde i Holland med 1000 indbyggere. Generelle dosis/respons-kurver fra litteraturen blev ikke anset for umiddelbart anvendelige til konsekvensundersøgelser i den lille bydel. I stedet er der benyttet en optimeret støjmodel, som er "kaliberet" i forhold til de faktisk målte støjniveauer i byen. Dosis-respons-kurver for lokalområdet er fundet ved at kombinere de målte støjniveauer (33 facademålepositioner) med resultatet af en spørgeskemaundersøgelse blandt 71 indbyggere. I undersøgelsen indgår både trafikstøj fra veje og jernbanen.

Der ses betydelige afvigelser i forhold til litteraturens generelle dosis/respons-forhold og de resultater, der kan opnås ved hjælp af standard støjudbredelses-beregninger (Dutch Standard Calculation Model for Traffic Noise). Der blev observeret en langt højere andel personer, der enten var stærkt generede af støjen og/eller havde søvnforstyrrelser. Beviserne for den akkumulerede effekt af sammensat støj fra vej- og togtrafik var ret begrænset. Dette kan skyldes deltagernes forskellige fortolkning af spørgeskemaets spørgsmål om sammensat støj og samtidig støj, som kan have været misvisende. En anden forklaring på afvigelserne fra de standardiserede dosis/respons-kurver er betydningen af trafikophobning i myldretiden, samt bidrag fra støjspidser og vibrationer. Deltagere nævnte bl.a. støj fra godstog om natten som årsag til søvnforstyrrelser.

Resultaterne af konsekvensanalysen for bydelen blev anvendt på fremtidige scenarier for byområdet, herunder foranstaltninger til at reducere trafikstøj fra vej og jernbane.

Social survey on wind turbine noise in Japan

Vol. 62, No.6, pp. 503-520, Kuwano, Sonoko; Yano, Takashi; Kageyama, Takayuki; Sueoka, Shinichi; Tachibana, Hideki

Som et led i en omfattende japansk undersøgelse af vindmøllestøjs påvirkning af mennesker har forfatterne både foretaget målinger, laboratorieforsøg og spørgeskemaundersøgelser. Det drejer sig om en 3-årig undersøgelse af vindmøllestøj fra 34 vindmølleparker samt støjen i 16 kontrolområder uden vindmøller. Der blev udført lydoptagelser over 120 timer, som blev analyseret i 1/3-oktaver for A-vægtede, C-vægtede og G-vægtede støjniveauer. Resultaterne fra undersøgelserne er fx publiceret i artiklerne: *Nationwide field measurements of wind turbine noise in Japan*, i Noise Control Engineering Journal, Vol. 62, No.2, pp. 90-101 samt i artiklen

Perception of low frequency components in wind turbine noise, Noise Control Engineering Journal Vol. 62, No.5, pp. 295-305.

I den aktuelle artikel i NCEJ Vol. 62 No.6 er resultaterne fra spørgeskemaundersøgelsen fremlagt. Undersøgelsen er som nævnt gennemført for 34 lokationer, hvor der var vindmøller i nærheden, samt i 16 lokationer uden vindmøller i nærheden. Antallet af adspurgte var 747 og 332 personer i henholdsvis vindmølleområderne og i kontrolområderne. I artiklen sammenlignes påvirkningen af beboerne i disse to områder mht. støjeksponering/respons for genevirkningen, søvnforstyrrelser og sundhedstilstand i relation til vindmøllestøj.

Vindmøllerne havde en effekt på mellem 400 og 3.000 kW, størstedelen større end 1.500 kW. Støjen fra møllerne blev målt i 7 punkter jævnt fordelt i afstandene 100 m til 1000 m samt i et referencepunkt tæt på møllen. Støjen ved naboerne blev ekstrapoleret på basis af regressionskurven for støjniveauerne i de 8 punkter.

Dosis/respons-kurverne for genevirkningen fra vejtrafik- og vindmøllestøjen viste, at vindmøllestøjen var 6-9 dB mere generende, målt som L_{dn} (dag-nat), end vejstøjen.

Vindmøllestøjen havde en effekt på søvnforstyrrelser for $L_{Aeq} > 40$ dB(A).

Der var intet bevis for, at selvrapporteret somatisk/mental helbredstilstand – udover søvn – var associeret med vindmøllestøj.

Den selvrapporterede støjfølsomhed var tydeligt forbundet med møllernes visuelle tilstedeværelse og med personernes somatiske/mentale helbredstilstand, hvilket tyder på at disse parametre i undersøgelsen viser egenskaber ved enkeltpersoner, som er nervøse over for miljøpåvirkninger eller forandringer i deres tilværelses balance, og som er tilbøjelige til at klage over søvn- og helbredsproblemer.

Evolving community noise ordinances in central Florida

Vol. 63, No. 2, pp. 109-116, Author: MacDonald, J.

Kun abstract læst.

Artiklen beskriver den seneste revision af bekendtgørelser for støj i 2 byer i det centrale Florida. I begge tilfælde var de eksisterende bekendtgørelser baseret på L_{max}-niveauer, hvilket havde vist sig at være ineffektivt til administration af støjen i lokalsamfundet. Bekendtgørelserne minder meget om de bekendtgørelser, der kan findes på tværs af USA. Metoderne i bekendtgørelserne var ikke pålidelige nok til at udpege lovovertrædelser. I artiklen beskrives den metodologi, der blev benyttet til at udforme en ny bekendtgørelse, der både opfylder behovene i samfundet og hos de lokale myndigheder, der skal håndhæve loven.

Effects of acoustic characteristics on annoyance of aircraft flyover noise

Vol 63, Nr. 3, pp. 279-286(8), Wang, Yachen; Liu, Shengnan; Dong, Yiwei; Cai, Jun

Artiklen er ikke fundet umiddelbart relevant.

3.5 Acta Acoustica

Årgang 2015: Vol. 101, No. 1 - 4 (januar/februar – juli/august)

Et link til dette tidsskrift findes i Bilag 1.

Modeling Temporal Integration of Loudness

Vol. 100, No.1, pp. 184-187, Hots, Jan; Rennies, Jan; Verhey, Jesko L.

Artiklen er ikke fundet umiddelbart relevant.

A Preliminary Examination of the Roles of Contextual Stimuli and Personality Traits Under the Adaptation Level Theory Model of Tinnitus

Vol. 100, No.3, pp. 543-551, Durai, M.; Kobayashi, K.; Searchfield, G. D.

Artiklen er ikke fundet umiddelbart relevant.

4. Kongresser

ICA - International Commission for Acoustics - har en liste over møder og kongresser på deres hjemmeside: www.icacommission.org/calendar.html.

4.1 Euronoise

Konferencen afholdtes forrige gang i forbindelse med "Ninth European Conference on Noise Control" den 10. - 13. juni 2012 i Prag, Tjekkiet.
Euronoise afholdtes sidste gang 31. maj - 3. juni 2015 i Maastricht, Holland.

www.euronoise2015.eu

4.2 Inter-Noise

Afholdtes forrige gang den 16. - 19. november 2014 i Melbourne, Australien (se Bilag 2).
Inter-Noise afholdtes sidst i San Francisco i Californien den 9. - 12. august 2015 og næste gang i 2016 i Hamburg.

www.internoise2014.com

www.internoise2015.com

http://www.internoise2016.org

4.3 International Conference on Noise as a Health Problem

Afholdtes forrige gang den 24. - 28. juli 2011 i London, England. Et kompendium herfra kan købes her: http://www.proceedings.com/12476.html

Konferencen afholdtes sidst den 1. - 5. juni 2014 i Nara, Japan. Proceedings kan downloades herfra: http://www.icben.org/Post_Congress_2014.html

4.4 Forum Acusticum

Afholdes hvert 3. år, forrige gang den 26. juni - 1. juli 2011 i Aalborg, Danmark. Afholdtes sidst den 7. - 12. september 2014 i Krakow, Polen.

Forum Acusticum afholdes næste gang i Boston den 25. - 29. juni 2017.

www.fa2011.org

www.fa2014.pl

https://www.euracoustics.org/news/eaa-newsletter/2014/november/Boston_2017.pdf

4.5 Baltic-Nordic Acoustics Meeting

Afholdes hvert 2. år, sidst den 2. - 4. juni 2014 i Tallinn, Estland.

Det næste Baltic-Nordic Acoustics Meeting vil blive afholdt på KTH i Stockholm den 20. - 22. juni 2016.

https://www.euracoustics.org/eaa-societies/partner-societies/nordic-acoustics-association/bnam-2014

https://www.kth.se/en/sci/2.66168

4.6 Low Frequency Noise and Vibration and its Control

Konferencen afholdtes sidste gang den 22. - 24. maj 2012 i Stratford upon Avon, England (15th International Conference on Low Frequency Noise and Vibration and its Control). Konferencen var planlagt afholdt den 29. september - 1. oktober 2014 i Berlin, men blev aflyst.

http://www.confweb.org/lfn2012/

http://www.confweb.org/lfn2014/

4.7 Wind Turbine Noise

Afholdes hvert 2. år, forrige gang den 27. - 30. august 2013 i Denver, USA. Afholdtes sidst den 20. - 23. april 2015 i Glasgow, Skotland. Konferencen i 2017 er endnu ikke fastlagt.

2013: http://www.lynlev.com/wtn2013/wordpress/

2015: http://windturbinenoise.eu/?page_id=121

Bilag 1

Links til tidsskrifters hjemmesider

Journal of the Acoustical Society of America (JASA)

http://scitation.aip.org/content/asa/journal/jasa/browse

Applied Acoustics

http://www.sciencedirect.com/science/journal/0003682X

Journal of Low-Frequency Noise, Vibration and Active Control

http://multi-science.metapress.com/content/121510/

Noise Control Engineering Journal

http://ince.publisher.ingentaconnect.com/content/ince/ncej

Acta Acustica

http://www.ingentaconnect.com/content/dav/aaua;jsessionid=2hrx8pvp3nh7.victoria

Bilag 2

Inter-Noise 2014 i Melbourne – udvalgte papers vedr. støj fra vindmøller

51 Special Noise Character in Noise from Wind Farms

Lenchine, Valeri V (1); Song, Jonathan (1)

(1) SA Environment Protection Authority, Australia

Noise produced by wind farms may exhibit a multitude of different noise characters, ranging from amplitude modulation, tonality and low frequency noise. The presence of the noise characters is able to increase the annoyance factor caused by a noise source significantly. A penalty to the noise levels is applied in accordance with some regulations when a noise character is detected. This paper discusses a noise character that can be described as "rumbling" that was detected during a long term monitoring program which was conducted in an area adjacent to a wind farm. The objective assessment of the data and subjective assessment of relevant audio records were performed to analyze the effect. The frequency spectra of the rumbling events indicate connection of the effect with low frequency noise and one of the low frequency components. The character was detected at low noise levels and might not be audible to a typical listener, however it is possible the character may cause an increased annoyance to people who have a higher sensitivity to the lower frequencies. Environmental conditions were also considered when discussing the occurrence of this noise character. The possible mechanism of the rumbling effect is suggested in the paper. The wind farm manufacturers may have to consider potential for low frequency impact of wind turbines and presence of prominent components at the design stage.

683 Investigating the impacts of wind turbine noise on quality of life in the Australian context: A case study approach.

McBride, David Iain (1); Shepherd, Daniel (2); Thorne, Robert (3)

(1) University of Otago, Dunedin, New Zealand
(2) Auckland University of Technology, New Zealand
(3) Massey University, Wellington, New Zealand

The WHO considers noise pollution to be of sufficient threat to public health to justify the publication of guidelines on noise effects and mitigation. 'Community noise' has largely been studied in the context of transportation and general neighbourhood noise, with exposure to wind turbine noise relatively understudied for historical, methodological, and political reasons. There also appears to be a general uncoupling of wind turbine noise from the other sources, which endows upon it an exclusivity that excuses it from the methods, guidelines, and critique used for other noise sources. This study aimed to advance understanding of wind turbine noise impacts by adopting a case study approach based on detailed information from 25 individuals,

Australian adults residing rurally and within 1000-3500m of three or more wind turbines. Participants were selected on the basis of health concerns evidenced through statutory declarations or submissions to hearings. The 25 respondents compeleted a face-to-face survey measuring health-related quality of life (HRQOL) questionnaire as developed by the World Health Organisation (WHO), the 'WHOQOL-BREF'. The results were compared to normative population data and showed clinically significant reduction in HRQOL.

685 Outcome of systematic research on wind turbine noise in Japan Part 1

Tachibana, Hideki, University of Tokyo, Japan

In Japan, serious complaints about wind turbine noise have arisen from nearby residents since the commencement of large-scale construction of wind generation plants in about 2000. Regarding this new type of environmental noise problem, scientific knowledge is insufficient and no standard methods for measuring and assessing the noise have been established in Japan. To improve this situation, a research project entitled "Research on the evaluation of human impact of low frequency noise from wind turbine generators" has been conducted over the three years from fiscal year 2010, funded by a grant from the Ministry of the Environment, Japan. This project consisted of three main subjects: (1) physical research on wind turbine noise by field measurement, (2) a social survey on the response of nearby residents, and (3) auditory experiments on the human response to noises containing low frequency components. In this paper, the outcome of the research project is reviewed and standard methods for measuring and assessing the wind turbine noise are discussed.

1026 Outcome of systematic research on wind turbine noise in Japan Part 2

Tachibana, Hideki, University of Tokyo, Japan

In Japan, serious complaints about wind turbine noise have arisen from nearby residents since the commencement of large-scale construction of wind generation plants in about 2000. Regarding this new type of environmental noise problem, scientific knowledge is insufficient and no standard methods for measuring and assessing the noise have been established in Japan. To improve this situation, a research project entitled "Research on the evaluation of human impact of low frequency noise from wind turbine generators" has been conducted over the three years from fiscal year 2010, funded by a grant from the Ministry of the Environment, Japan. This project consisted of three main subjects: (1) physical research on wind turbine noise by field measurement, (2) a social survey on the response of nearby residents, and (3) auditory experiments on the human response to noises containing low frequency components. In this paper, the outcome of the research project is reviewed and standard methods for measuring and assessing the wind turbine noise are discussed.

844 An investigation of Different Secondary Noise Wind Screen Designs for Wind Turbine Noise Applications

Novak, Colin (1); Sjöström, Anders (2); Ule, Helen (3); Bard, Delphine (2); Sandberg, Göran (2)

(1) University of Windsor, Canada
(2) Lund University, Sweden
(3) Akoustik Engineering Limited, Canada

The use of diaphragm type microphones with the typical foam windscreen ball for outdoor noise measurement applications are mostly restricted to wind speeds below 4 to 6 m/s. This is due to the extra noise induced into the microphone, particularly at low and infrasonic frequencies, as a result of the wind excitation on the diaphragm. For wind turbine noise measurement applications, it is often necessary to measure the turbine noise under the typical operating conditions with wind speeds up to 12 m/s. This introduces a problem in the measurement system, as the normal microphone setup and windscreen are not adequate at these elevated wind speeds. Secondary windscreens, such as for example that prescribed by IEC 64100-11, "Acoustic noise measurement techniques" imparts their own problems including ridged body motion of the windscreen structure due to turbulence. Also, ground plane secondary windscreen measures the noise at ground level, instead of at ear level. This study investigates the use of several secondary windscreens with microphones capable of measuring at infrasonic frequencies for measuring wind turbine noise at elevated wind speeds. The result was that no windscreen provided a full solution to the problem. Specific recommendations for additional windscreen design and investigation are included.

472 Wind turbine sound - metric and guidelines

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The meteorological conditions vary over the globe but also change over the day and the year and vary a lot depending on the terrain for a certain location. The meteorological parameters govern both the wind turbine emission sound levels and the sound propagation conditions and therefore gives rise to different sound immission levels. Long-time measurements of meteorological effects on sound propagation from wind turbines over forest areas have been performed at two sites in Sweden for more than two years. One site is located in the southern part with flat terrain and the other site is located in the northern part of Sweden with more hilly terrain. The aim of the project is to improve the knowledge of sound propagation from wind turbines and especially over varying terrain and weather conditions. Control measurements of wind turbine immission sound levels will be needed to see that they fulfill the noise regulations. It is therefore of most importance to be able to make representative measurements. Discussions about under what meteorological conditions the immission measurements have to be carried out, the sound metric and the impact of the guidelines are presented in this paper.

287 Wind turbine noise measurements - How are results influenced by different methods of deriving wind speed?

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With the increasing number of operational wind farms/turbines, the requirement for noise measurements required to demonstrate compliance with planning conditions is increasing as well. The British ETSU-R-97 noise limits are often set relative to measured or standardised 10 m height wind speeds and therefore the assessment of noise from wind turbines requires simultaneous noise and wind speed/direction measurements. For financial reasons, smaller and single turbine sites are often not equipped with a meteorological mast. If no independent hub height wind measurements are available, wind speed is either taken from nacelle anemometers or derived from power measurements combined with the power curve for the respective wind turbine type. Noise measurements referenced to nacelle anemometer data will be compared with the same measurements but correlated with derived power curve wind speed, and measured wind data from separate met mast or other remote sensing devices. The influence of incorrect filtering of wind data for shadow effects (mast and/or nearby wind turbines) on the noise assessment may be presented, depending on how much time is available. The advantages and disadvantages of the various methods will be discussed.

171 Correlation of amplitude modulation to inflow characteristics

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Amplitude modulation (AM) of noise from wind turbines and its more extreme version named "other amplitude modulation" OAM have been investigated intensively during the last few years due to the additional annoyance impact this type of noise has compared to broad band noise. In a recent published research by RenewableUK the hypothesis has been that one of the causes of OAM is transient stall on the blade due to non uniform inflow such as shear. Part of the RenewableUK research work was a contribution by DTU on analysis of data from the DANAERO MW experiment from 2009. In the DANAERO experiment a new 38.8m test blade for a 2MW NM80 turbine was manufactured and equipped with a massive instrumentation comprising flush mounted surface microphones, pressure taps and five hole pitot tubes. The correlation of the spectra from the surface microphones and the measured inflow angle (IA) confirmed the strong increase in the noise source for high IA. As only few 10min data sets were measured in the DANAERO project a data set with measured inflow angle from 2003 on the same turbine has been used to explore the statistical properties of AM and OAM based on assumed correlation to IA.

432 Using Wind Farm Noise Auralisations for Effective Community Consultation

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Two of the most common questions that wind farm developers face during community consultation are 'what will the wind farm look like' and 'what noise will it make?' A lot of work has been undertaken recently to develop 'visualisations' or 'photomontages' to answer the first question. However, there has not been an equivalent tool available to enable local communities to understand what a wind farm actually sounds like. Arup and Hydro Tasmania have jointly developed a tool that will accurately and effectively communicate what a wind farm sounds like under different wind conditions and from a range of distances and orientations. This auralisation tool provides a practical and affordable means for the industry to effectively communicate what a wind farm will sound like to the community. This paper looks at how auralisation techniques used in other sectors (such as transport and aviation) have been adapted for the renewable wind energy sector and serve as a valuable tool for increasing transparency, minimising risk and building trust within local communities early in the wind farm development process. It shows how a comprehensive field measurement program at Studland Bay Wind Farm, Tasmania has enabled a wind turbine sound library to be developed for future use in wind farm acoustic models and how calibrated auralisations can be presented at community settings.

1002 The noise characteristics of 'compliant' wind farms that adversely affect its neighbours

Large, Sarah (1); Stigwood, Mike (1)

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In the UK many wind farms cause complaints of noise despite complying with control limits. Problems relate to reliance on the LA90 index, failure to consider or apply ratings on the context of the sound characteristics and actual human responses due to complex characteristics. In general in the UK low frequency and very low frequency sound effects are either ignored or denied. The complex interrelationship of features within this noise and difficulties in quantifying and qualifying noise impact and inappropriate comparison with other sources of noise renders the effects difficult to investigate or quantify with contradictory outcomes possible using the same data sets. Claim and counterclaim of health and adverse effects complicate the analysis. This paper explores some of the interrelating characteristics of wind farm noise measured and observed in the field that appear to influence complaints made by communities. Cumulative effects occurring in environments normally dominated by natural sounds and both audible and inaudible elements remain alien sounds which are not habituated to. It appears that sensitisation arises. The physical reason for the failure to appropriately identify modulating noise effects and in particular low frequency modulating noise problems are explored.

597 The Relevance of the Precautionary Principle to wind farm noise planning

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Wind farms consist of clusters of industrial wind turbines which, when placed in rural areas, are associated with intrusive and unwanted sound. Wind turbine noise has characteristics sufficiently different from other, more extensively studied, noise sources to suggest that standard industrial noise standards are not appropriate for measurement and assessment purposes. A seven year study is reported and, although limited in population size, it is clear that there are definite adverse health effects related to wind farm noise. Time-aggregated noise metrics have limited utility in assessing individual human health and well-being, and a cluster of metrics are needed to describe and estimate potential effects on individuals and communities. Sleep deprivation is a widely reported occurrence by people in the vicinity of a wind farm. At this time, however, the quantity and quality of research are insufficient to effectively describe the relationship between wind turbine noise and health, and until such time that a definitive relationship is obtained, legislation should apply the precautionary principle and conservative criteria when assessing proposed wind farm developments.

1001 Initial findings of the UK Cotton Farm Wind Farm long term community noise monitoring project

Stigwood, Mike (1); Stigwood, Duncan (1); Large, Sarah (1)

(1) MAS Environmental, UK

This paper provides early results of a long term study of community impact from wind farm noise and uses of the data obtained. A continuously recorded database of noise collected under different meteorological conditions has allowed detailed analysis of particular characteristics such as amplitude modulation and also the reliability of assessment methodologies for predicting and quantifying impact. Surprising outcomes are explored including upwind impact. In 2013 MAS Environmental established a permanent monitoring station to record and publish data online located 600m from the nearest turbine to correlate the impact upon the community and provide an extensive database. This paper maps the evolution of the project. Online data enables a wider study of the effect of meteorological change on noise immission in a flat eastern area of the UK. Anyone can independently observe and listen to the audible elements of the noise that people complain about. This tool aids understanding as well as predicting times of likely adverse impact. The database has enabled testing of proposed controls, particularly in relation to audible amplitude modulation and demonstrated the recent Renewables UK proposed control mechanism fails. Data obtained challenges blade stall research claims as the primary cause of far field AM and wind farm noise prediction methodologies.

490 Application of stochastic wind model to investigate swishing characteristics of infrasound and low frequency noise from wind turbine

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Swishing characteristics of infrasound and low frequency noise radiating from a modern large horizontal-axis wind turbine are investigated by employing stochastic wind model to reproduce realistic incident wind conditions upstream of the wind turbine. The stochastic wind is generated through the superposition of colored noise on mean wind profile. The colored noise is computed by applying low-pass filter to white noise. The filter represents the geometric and atmospheric conditions around the target turbine. The wind profiles generated in this way are applied to compute aerodynamic response on blades of the wind turbine by using the XFOIL code. The computed airfoil response is finally incorporated to predict the infrasound and low frequency noise of the wind turbine by using the Lowson's acoustic analogy. When only the mean wind profile is applied, the swishing effects in the predicted time-frequency maps of the wind turbine noise are clearly identified. However, unsteadiness in the incident wind profile leads to more complex swishing characteristics, which are often found in the noise signals obtained from field measurements. This result implies that operational condition on site in which the wind turbine is installed needs to be taken into account to more accurately assess the sound quality of wind turbine noise due to its swishing.

551 Cyclic pitch for the control of wind turbine noise amplitude modulation

Bertagnolio, Franck (1); Madsen, Helge Aagaard (1); Fischer, Andreas (1); Bak, Christian (1)

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Using experimental data acquired during a wind turbine measurement campaign, it is shown that amplitude modulation of aerodynamic noise can be generated by the rotating blades in conjunction with the atmospheric wind shear. As an attempt to alleviate this phenomenon, a control strategy is designed in form of a cyclic pitch of the blades. As a side effect, it is shown that it is also possible to reduce fatigue load on the blade using this cyclic pitch. The main goal is to reduce both amplitude modulation and fatigue load without compro- mising the energy harvested from the wind. A simulation tool that can model the different aerodynamic and aeroacoustic aspects of the study is presented. Parameters controlling the cyclic pitch are optimized in order to reduce amplitude modulation and/or fatigue load to a minimum. It is shown that such a minimum can be found and that benefit may be achieved if such a strategy is to be implemented on an actual wind turbine, though at the expense of an increased wear and tear of the pitch control system.

385 Tonal characteristics of wind turbine drive trains

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Wind turbines use a drive train incorporating a rotor, gearbox and generator to harness power from turning of the turbine blades. Modern wind turbine drive trains utilise a multi-stage gearbox, typically involving a planetary gear stage (low speed shaft) and two parallel stages (mid and high speed shafts). These gearboxes have natural frequencies and mode-shapes dependent upon the stiffness of gear shafts and tooth pairs, which can interact with tonal sources such as gear meshing frequencies to result in audible tones, and greatly increase the annoyance factor of wind farms and adversely impact on human health. This paper examines the drive train of a wind turbine, the impact on environmental noise emissions from the turbine, and how tonal characteristic issues associated with its operation may be avoided.

972 Wind Turbine Tower Resonance

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Wind turbine towers are large structures designed to withstand the unique loading conditions imposed on them by the turbine's nacelle and dynamic forces from the rotating blades. Observations and noise measurements of a particular wind turbine showed high noise levels at approximately 48 Hz, which could not be explained from the usual known potential noise sources. Correlated far field noise measurements and vibration measurements collected on the turbine tower, structural base and nearby ground have shown the source to be a resonance of the tower structure.

296 Numerical simulation and aeroacoustic noise modelling of a wind turbine using a blade section in an annulus

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Noise disturbance from wind turbines is one of the major factors which slows wind farm development near populated areas. Therefore, it is important to have an accurate estimate of the noise generated before production and installation of wind turbines. Large Eddy Simulation (LES) can be used to determine the aerodynamic sound produced by a moving surface, but LES of a whole wind turbine is computationally expensive. However, Oerlemans' field measurements show that most of the noise from wind turbines is generated at 75%-95% of the span of the blade. This suggests that simulation of a section with the most significant noise sources could lead to a useful overall noise estimate in the far field. The present work is focused on

noise prediction from a wind turbine using a rotational annulus containing a section of a wind turbine blade, which leads to a significant reduction of computational expense. LES with the Ffowcs-Williams and Hawkings acoustic analogy is used to predict the far field acoustic noise. Initial results with rotational CART-2 wind turbine blade show good agreement with the available experimental data.

451 Classification of damage for planetary gear of wind turbine simulator

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A planetary gear of a wind turbine is a critical component in the view of condition monitoring and fault detection because the fault of the gear needs much cost and time to fix or replace it. In this paper, classification of damage for a planetary gear is proposed and validated by the experiment of wind turbine simulator in order to evaluate the possibility of the application to fault detection of a real wind turbine. Vibration data for various faults of a gear are acquired in wind turbine simulator. Then, effective metrics induced by the gathered vibration data are determined by using vibration data with constant rotational speed. Finally, classification of damage is performed by using neural network with normalized features and bin concept when rotational speed of wind turbine simulator is varied.

199 Influence of non-standard atmospheric conditions on turbine noise levels near wind farms

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This paper investigates the accuracy of wind turbine noise predictions under non-standard meteorological conditions. It reviews studies into the influence of meteorological variables on noise emission and propagation. In particular, it presents recent extended wind farm noise measurements undertaken by the authors to investigate the effects of periods of higher wind shear on noise propagation. Wind turbine noise levels were measured at a location 1150 m from a wind farm where wind shear was simultaneously monitored. It is found that wind shear tends to have a negligible influence on noise propagation for the range of operating conditions of the wind farm. The influence of wind direction on noise levels at the monitoring location was found to be much larger than that of wind shear.

800 Assessing the Validity of Wind Farm Noise Monitoring Data for Periods of Partial Wind Farm Operation

Mitchell, Andrew

AECOM, Australia

Wind farm noise compliance assessments require measurement of the wind farm noise under full operating conditions. Normal wind farm operation typically includes periods where one or more wind turbines may be unable to operate, due to maintenance requirements, grid restrictions, or other factors. For a large wind farm with many wind turbines, or in situations where cumulative noise impacts from other wind farms need to be considered, there may be very few periods where all wind turbines at the wind farm, and any neighbouring wind farm, operate simultaneously. In such scenarios it is rarely practicable to simply take noise monitoring data from only the periods where all wind turbines were operating, as this may involve excluding a significant proportion of the noise monitoring data set, which would result in a considerable increase in the duration of noise monitoring that is necessary to obtain the required size of data set. To reduce the proportion of data that needs to be excluded, noise modelling can be used to determine whether the combination of wind turbines operating at any particular time would have resulted in a materially lower noise level than would have occurred with all wind turbines operating. Based on such modelling, non-representative noise measurement data can be excluded from the assessment. This paper discusses a data exclusion methodology that has previously been used for wind farm noise assessments in Australia, and investigates the effect that various modelling simplifications and exclusion criteria could have on the noise assessment outcome, based on a case study of noise monitoring data from 18 locations at two large Australian wind farms. For the case studies investigated it was found that the effect of excluding periods of noise data where there were non-operational wind turbines was minor, and the exclusion of such data could possibly be an unnecessary step in practical noise assessments for large wind farms, when using the assessment methodologies in use in Australia.

829 Noise Propagation from a Vertical Axis Wind Turbine

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Initial noise measurements were performed on a 200kW vertical axis wind turbine (VAWT) and results were compared to that of a Vestas V27, a similar size horizontal axis wind turbine (HAWT). Multiple recording units were placed in line downwind of the turbine to investigate noise propagation. The frequency distribution of the noise were analyzed indicating that the VAWT has lower relative levels for frequencies under 3000 Hz, especially within 600-1200 Hz. Furthermore, VAWT noise seems to occur more around the same frequencies as the natural background noise, increasing masking probability. Results from propagation measurements seemed to indicate that noise declines more rapidly with distance for the VAWT then for the reference HAWT, possibly explained by the lower levels at low frequencies. Further investiga-

tion is needed to establish these differences and the 200 kW VAWT creates an opportunity doing so utilizing arguably the largest operational VAWT existing today.

465 Wind turbine noise: practical immission measurements

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For 15 years the number of wind turbines installed in Europe has increased rapidly. In this framework many objections are expressed towards the sound emitted during the Wind Turbine (WT) working and its perception as a noise in the direct neighbourhood. The noise is due to aerodynamic interactions with the blades of WTs. After its propagation over several hundred meters, the noise is more or less stationary but can feature an amplitude modulation that can be very annoying for the human hearing. To understand the physical causes of this potential annoyance, some noise measurements were carried out. A lot of care is necessary to have relevant recordings of the WT noise. The measurement precautions are explained as well as the data processing to avoid the periods with a dominant background noise. Finally some results of measurement campaigns are exposed.