A review of research into the human response to amplitude-modulated wind turbine noise and development of a planning control method

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ABSTRACT

WSP | Parsons Brinckerhoff was commissioned by the United Kingdom (UK) Government Department of Energy and Climate Change (DECC) to undertake a review of research into the effects of and response to the acoustic character of wind turbine noise known as Amplitude Modulation (AM). More specifically the review dealt with the increased level of modulation of aerodynamic noise as perceived at neighbouring dwellings, with a view to providing protection where it is justified within the planning regime.

This paper describes how the literature review was undertaken and the key findings from the review of those papers on the state of knowledge of AM, its effect on people, and the dose-response relationships that exist. It goes on to highlight the gaps in the knowledge base, the risks of bias in the studies reviewed, and how those deficiencies can be overcome in the short term in the absence of a new dose response study. Also described are potential methods to control AM, an approach to quantifying the potential impact on energy yields during periods of control, the recommended method suggested to DECC, and how that condition may be written in accordance with UK Planning Policy.

Keywords: Wind turbine noise, Amplitude modulation, Exposure-response, Annoyance, Planning
I-INCE Classification of Subjects Number(s): 14.5.4, 52.9, 61.6, 62.5, 63.2, 63.4, 63.7, 66.1, 67.1, 68.3, 68.7, 69.3, 69.5, 72.9, 82

1. INTRODUCTION

In wind turbine noise (WTN), continuous modulation of the amplitude envelope occurs during rotor revolution, producing sounds commonly described as 'swish', or sometimes as 'thump' (1). As has been highlighted, amplitude modulation (AM) of WTN is an important factor in determining the subjective response (2, 3). Industry and public concern about WTN AM has been growing in the UK over recent years, although the extent of the issue is not fully understood. A recent study of wind farm impacts in Scotland indicated that AM could be perceived by residents in around two thirds of the ten case study sites, however specifics about the AM (such as the magnitude) were less clear (4). The study also noted that a large majority of the surveyed residents were not affected by noise from the wind farms. A national survey of noise attitudes (SoNA) and annoyance in the UK has recently been published (5); the fact that wind farm noise does not feature in the key findings may reflect the relatively small proportion of the UK population exposed to WTN. Nonetheless, wind farm noise can be a significant and highly emotive issue for those involved (6, 7, 8), and has been shown to induce greater annoyance in individuals compared with other environmental noises (9).

Existing planning policy in the UK refers to the ETSU-R-97 guidance for assessment of the potential noise impact of new wind farms (10). The approach in this document is supplemented by a

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Good Practice Guide (11) published by the UK Institute of Acoustics (IOA). The ETSU-R-97 guidance was based on an assumed component of AM in the form of 'blade swish', typically noticeable only in relatively near proximity to the source. The emergence of a form of AM that could be audible at long distance and with a lower frequency character ('thump'), together with the reported difficulties in applying Statutory Nuisance provisions to control AM on existing sites, has highlighted a need for a planning mechanism to control the potential impact of AM WTN from proposed wind farms. This research was commissioned by DECC to inform the development of a suitable control.

2. Project Overview

2.1 Aims

The objective of the research was to review the available scientific evidence concerning the human response to AM, evaluate the robustness of identified exposure-response relationships, and make a recommendation as to how a suitable control for AM might be implemented within the current UK planning system for wind farms. It was envisaged that, if sufficient supporting evidence was found, this could take the form of a rating penalty system, similar in concept to existing approaches to quantifying acoustic characteristics in wind turbine and environmental noise (12, 13). The brief also included the aim to work closely with the UK Institute of Acoustics AM Working Group (IOA AMWG), which has independently researched and developed a method to detect and rate (in terms of physical magnitude) the AM in a wind turbine noise signal (14).

2.2 Project Team and Government Steering Group

The project was led by researchers at WSP | Parsons Brinckerhoff, supported by a group of external independent noise and health specialists.

The work was directed by a Steering Group, comprising representatives of DECC, the Department for Environment, Food and Rural Affairs (DEFRA), the Department for Communities and Local Government (DCLG), Public Health England (PHE), and the Devolved Authorities.

2.3 Structure

The project was undertaken in two Phases: in Phase One the approach was agreed and relevant stakeholders, information sources and search techniques identified. Phase Two comprised the research review and evaluation process, and the drafting of the findings and recommendations, including an external independent peer review and feedback period.

3. Review of Evidence

3.1 Approach

The following information sources were searched:

- Web of Science;
- PubMed;
- Conference Proceedings:
    - International Commission on the Biological Effects of Noise (ICBEN) Congress;
    - International Meeting/Conference on Wind Turbine Noise (INCE Europe);
    - International Meeting on Low Frequency Noise and Vibration;
    - International Congress on Sound and Vibration (ICSV);
    - European Congress and Exposition on Noise Control Engineering (Euronoise); and
    - International Congress and Exposition on Noise Control Engineering (Inter-noise);
- Industry publications:
    - RenewableUK research reports;
    - IOA AMWG reports;
    - Reports by the UK Independent Noise Working Group (INWG); and
    - Institutional or Government-affiliated research reports on wind turbine noise.

Initially, the search results were examined by title and abstract, and papers with potential relevance listed. The sifting process highlighted a range of categories of study, which were separated according to classification. The papers identified were categorised as follows:

1. Primary study identifying the AM WTN human exposure-response relationship, i.e. both a

quantified AM WTN component and a scaled human response;

2. Supplementary study:
   a. Examination of elements of the AM WTN human exposure-response relationship that did not meet the category 1 criteria;
   b. Case-study of AM WTN, including a quantified exposure and an unscaled response (typically complaints);
   c. Quantified exposure to a non-WTN AM source together with a scaled response;
   d. Research identifying both a quantified WTN component (but without isolating AM) and a scaled human response;
   e. Investigation into other potentially-relevant aspects of WTN-related AM or LFN (as a possible proxy for AM); and
   f. Examination of existing or proposed planning controls relating to AM WTN.

The abstracts of each remaining paper identified on the 'longlist' were examined. These papers were assigned a 0-9 rating of potential relevance against the study aims, which was used to prioritise the reviews of papers in each category. A total of 134 papers were identified, of which 69 were shortlisted for more detailed review. Of these, 15 papers were assigned to Category 1. One additional Category 1 study was identified after completion of the review stage (i.e. bringing the total papers identified for consideration to 135).

Reviews of each paper were carried out according to a bespoke structured review template to systemise the responses, prompting all reviewers to follow the same format and extract the same set of information from each paper (where available). The review template has been included as an appendix to the published report (15).

3.2 Potential for Bias

Potential publication bias in the search phase was minimised by accessing established reputable databases covering peer-reviewed ('black') literature in both science and health-related fields, and including 'grey' literature sources such as conference papers and industry publications.

The potential effects of selection bias (due to the application of relevance ratings and the categorisation process) are considered unlikely to be significant, mainly due to the relatively small number of studies directly examining the AM WTN exposure-response relationship, i.e. Category 1. Category 2 material mainly provided supporting and contextual information and so any effects in terms of outcomes for the research are not be expected to be critical.

Risk of bias within the reviews was minimised by assigning each Category 1 paper to two external reviewers and resolving differences via discussion. The initial findings of the study were also subjected to an external independent peer-review phase, feedback from which was incorporated into the final draft.

3.3 Outcomes

A simplified schematic for possible factors important in AM WTN exposure-response is illustrated in Figure 1. The components making up this model are discussed below.

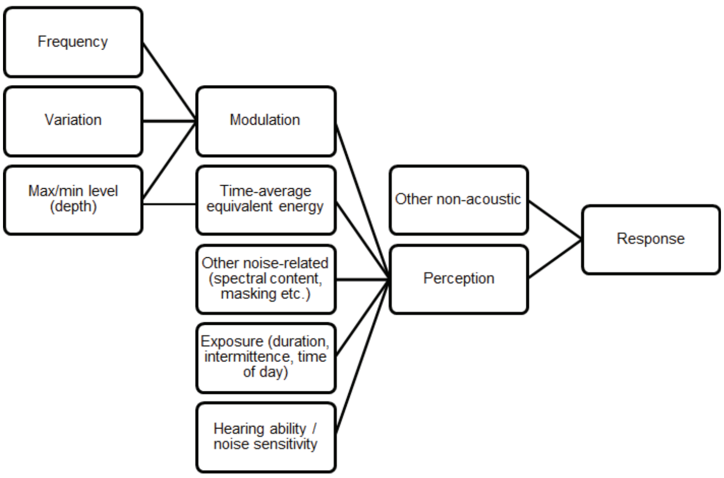

Figure 1 – Proposed schematic model for AM WTN exposure-response factors

Several studies examine the possible effects of WTN on health, including annoyance, but very few specifically examine the influence of the AM component. Reviews of the research into health effects have indicated that the clearest consistent directly-induced effect of WTN is annoyance (16, 17, 18, 19, 20, 21, 22). Evidence for sleep disturbance and stress exists but is weaker, suggesting a predominantly indirect path via annoyance and other factors, rather than as a direct result of exposure to WTN at typical levels. More-recent, large-scale epidemiological field studies in Canada and Japan (23, 24, 25) also show apparent inconsistency regarding sleep disturbance: self-reported adverse effects on sleep for WTN >40 dB L_{Aeq} were found in ref. (23), whereas refs. (24, 25) showed no significant effect for WTN up to 46dB L_{Aeq}, employing objective measurements of sleep disturbance alongside self-reporting. In view of this, the present study is focussed on the annoyance response.

3.3.1 Influence of modulation

Lee et al. (26, 27) performed a laboratory test with 30 subjects, exposing them to a set of stimuli formed from close-range AM WTN recordings combined with filtered white noise, and recording annoyance ratings on an ISO-derived scale (28). The hybrid 30-second samples allowed the selected Fourier-derived spectral maximum modulation depth parameter to be closely controlled. Two fundamentally different spectral characters were examined[3], producing different MD ranges, as illustrated in Figure 2.

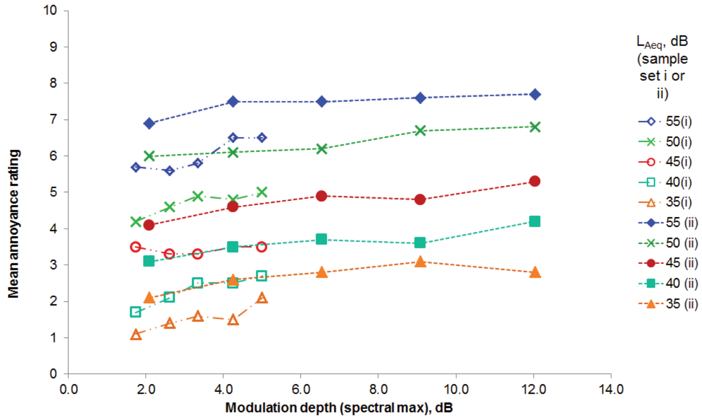

Figure 2 – Wind turbine AM exposure-response relationships identified by Lee et al. (26, 27)[4]

Statistically significant differences in mean annoyance ratings relative to MD were found only in paired comparisons of the relative extrema of the cases (e.g. significant differences in stimuli set (ii) were shown by comparing 2.1 dB MD against 9.1 dB and 12.0 dB MD, but not for smaller differences).

Von Hünerbein et al. (29, 30) investigated a range of possible factors influencing annoyance responses to simulated, 30-second AM WTN stimuli. These included modulation frequency (MF), spectral content, MD and envelope shape. Here, MD was defined in terms of the mean levels of peaks and troughs in the L_{Aeq} envelope. A sample of 20 subjects recorded absolute annoyance ratings on a scale similar to ref (28), as shown in Figure 3 (left). Despite an observable consistent trend, MD was not found to have a significant effect on absolute annoyance, thought to be due primarily to the small sample size.

In another experiment, subjects were asked to adjust the level of a steady broadband noise to match an AM stimulus in annoyance. The results are shown in Figure 3 (right) as level differences relative to the L_{Aeq} of the AM signal. An apparent anomaly is shown for 0 dB MD (i.e. a comparison between identical stimuli), attributed to potential confusion or expectation bias amongst participants. The results for the average relative adjustments are approximately equal for 3 dB MD and above; 2.3 dB was the average adjustment for all stimuli, 3.5 dB for a 30 dB(A) sound, and 1.5 dB for a 40 dB(A) sound. Again, the artificiality of the experiment makes interpretation of the results in terms of absolute annoyance difficult, but the relative ratings and trends observed still provide useful insights into the underlying relationships.

Bockstael et al. (31, 32) conducted a field study investigating how alterations in wind turbine operational parameters could influence the annoyance reported by residents near a turbine site with a history of noise complaints and an extant operational control regime in place (to mitigate noise). Eight participating households were engaged in the vicinity, of which three provided regular input over six

[3] Sample (i) contained more energy at lower frequencies than sample (ii).
[4] Data from Lee, S, et al., 2009 (26).

months via online reporting of their level of annoyance against an adapted ISO scale (28). The AM component was quantified from the measured data using a 'fluctuation indicator' derived from Fourier analysis of the third-octave filtered amplitude envelope time series. The results are shown in Figure 4.

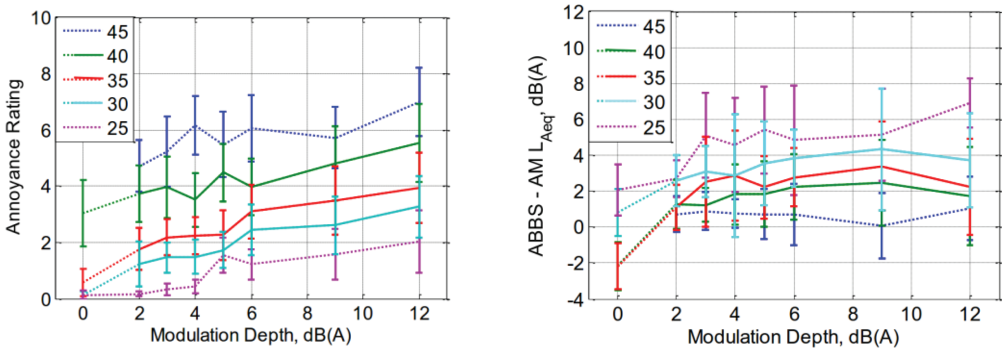

Figure 3 – Wind turbine AM exposure-response relationships identified by von Hünerbein et al. (29, 30)[5]; left: absolute annoyance ratings; right: relative annoyance adjustments; errorbars indicate 95% confidence intervals around the mean; dotted lines indicate results from reduced sample size

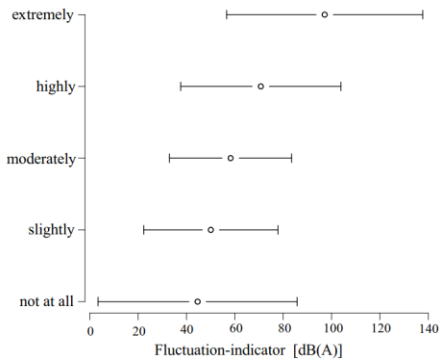

Figure 4 – Wind turbine AM exposure-response relationship identified by Bockstael et al. (31, 32)[6]; errorbars show +/- one standard deviation from the 10-minute maximal mean

A relationship between the derived AM fluctuation indicator and the reported annoyance ratings is observed, although the variance in responses is sufficiently wide that AM of a relatively slight degree could induce a 'not at all' annoyance rating from some respondents but 'extremely annoyed' from a number of others. This is probably due in part to the small sample size, but may also reflect limitations in the measurement setup, or subjective responses influenced by factors other than the AM perceived. Another issue with this study is the choice of AM metric (designed to work with real, 'noisy' data rather than the the controllable stimuli used in laboratory studies) and the lack of a direct conversion/comparison with MD, which restricts comparability with other studies in this category. There is also a risk of selection and response bias in the annoyance ratings, due to the problematic history of the site and the small sample size. On the other hand, the results have the advantage of being sampled from a WTN-exposed population, with exposure set within a real sensitivity context.

Yokoyama et al. (33, 34, 35, 36) investigated the perception of simulated AM WTN in a laboratory experiment conducted with 17 subjects. The focus of the study on perception is different to the other studies discussed, which concentrate on a response (annoyance). The onset of 'fluctuation sensation' was determined as just under 2 dB MD (ΔL) for two-thirds of subjects, as shown in Figure 5.

In a similar way to the adjustment experiment in ref. (29), the relative perception of AM WTN was investigated by a method of adjustment; participants changed the level of an AM stimulus until it matched a steady broadband equivalent in 'perceived noisiness'. The results, shown in Figure 6, indicate increasing average adjustments with MD, as well as increasing spread in the results. Average adjustments were around 0.5 dB to 1.5 dB for MDs of 3-4 dB, and around 1.5 dB to 3.5 dB for MDs of 6-10 dB.

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[5] Figure reproduced from von Hünerbein, S, et al., 2013 (29), with the permission of RenewableUK.
[6] Figure reproduced from Bockstael, A, et al., 2012 (32), DOI: 10.3813/AAA.918524, with the permission of S. Hirzel Verlag.

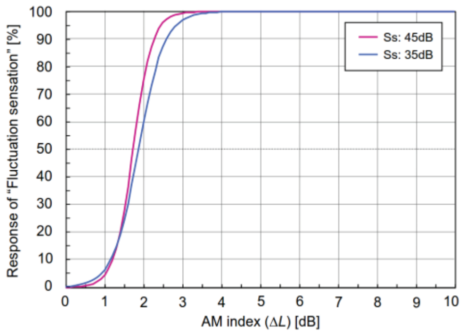

Figure 5 – Wind turbine AM exposure-perception relationship identified by Yokoyama et al. (33, 36)[7]

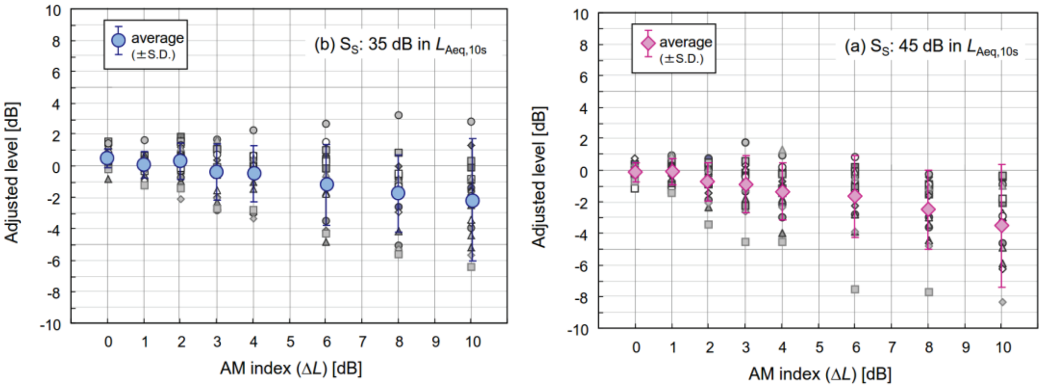

Figure 6 – Wind turbine AM exposure-perception relationship identified by Yokoyama et al. (33, 36)[7]

Ioannidou et al. (37) examined the influence of variations in MD, MF, and intermittent changes in AM over time on the absolute annoyance ratings of 19 subjects using hybrid recordings/synthesised stimuli (30s samples). The same spectral MD indicator as ref. (26) was derived, and results for the mean values are shown in Figure 7.

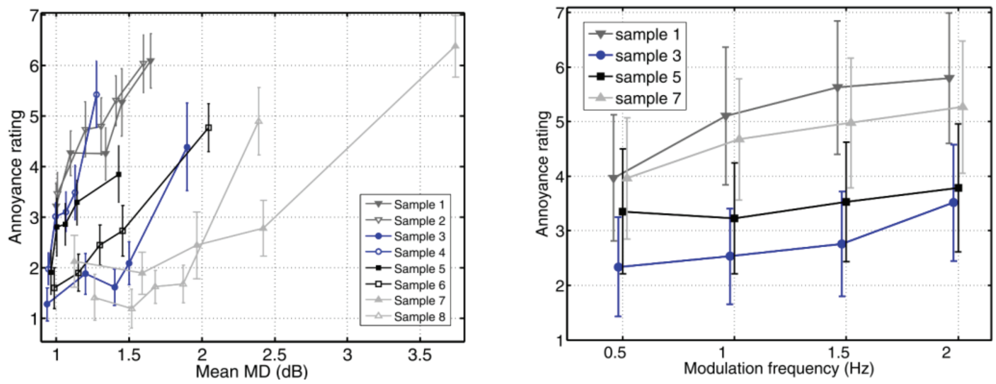

Figure 7 – Wind turbine AM exposure-response relationships identified by Ioannidou et al. (37)[8]; left: modulation depth; right: modulation frequency

The analysis identified a significant effect of MD on annoyance ratings, as well as a significant effect of the variation between samples, which had differing spectral characteristics and MFs. When these factors were controlled for, by comparing results within each sample type, the 'relative modulation strength' showed a consistently increasing effect on annoyance.

The effect of MF varying over the range 0.5 Hz to 2 Hz was also directly investigated, producing the observable increasing trend illustrated in Figure 7, but was not found to have a significant effect on annoyance.

This result shows agreement with results from ref. (29) in which the MF, varied binarily between 0.8 Hz and 1.5 Hz, showed a similarly observable influence on absolute annoyance, with the higher MF increasing the annoyance rating. Both observations concur with the results in refs. (38, 39, 40),

[7] Figures reproduced from Yokoyama, S, et al., 2015 (36), with the permission of the authors.
[8] Figure reproduced from Ioannidou, C, et al., 2016 (37), DOI: 10.1121/1.4944570, with the permission of the Acoustical Society of America.

which suggest that sensitivity to AM broadband noise is greatest for MFs of around 2 to 10 Hz, peaking around 4 Hz; this is thought to be due to typical human speech modulation rates. The relatively slight results for WTN reflect the limited range of MF for typical large-scale turbines, for which AM is typically within the 0.5 to 1.5 Hz range.

Results from laboratory experiments with other broadband non-WTN AM sounds suggest an 'equivalent annoyance' compared with a steady noise of around 4-5 dB (41, 42).

3.3.2 Influence of spectral content

The influence of AM spectral content on response, which is relevant to the 'swish'/'thump' distinction mentioned earlier, was investigated in refs. (26, 29, 36, 37). The results obtained in these studies indicate that the spectral content is less straightforward in determining a response than might be presumed; tests in refs. (26) and (29) suggested that the higher-frequency stimuli induced slightly greater annoyance than lower frequency AM content, while those in ref. (37) showed that subjects did not find samples with intermittent periods of OAM[9] significantly more annoying than an equivalent with the same mean MD outside the OAM periods.

3.3.3 Influence of time-averaged equivalent energy

As referenced above, field studies have shown that the overall level of WTN has a strong effect on annoyance. The relative strength of this effect compared with MD can be examined in studies that have controlled the AM component alongside the time-averaged energy. Results from refs. (26, 29) are illustrated in Figure 8.

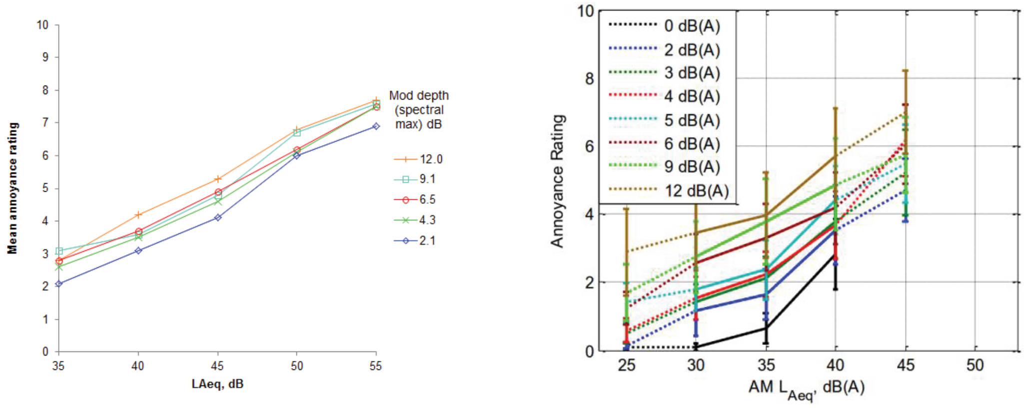

Figure 8 – Wind turbine AM exposure-response relationships identified by (left) Lee, S et al. (26, 27)[10] and by (right) von Hünerbein, S et al., (29, 30)[11]

The results of these studies indicate a strong and significant relationship between time-averaged equivalent energy level and annoyance for AM WTN.

In a laboratory experiment by Seong et al. (43, 44), 32 subjects rated annoyance from 15s samples of simulated AM WTN, adjusted for a range of distances and incidence angles. The highest ratings for annoyance were recorded in the direction from the turbine in which the combination of modulation depth and level were highest (44, 45).

Van den Berg (46) has shown that the addition of a 5 dB penalty for AM character to the WTN time-average level exposure-response annoyance curve from ref. (9) brings this largely within bounds formed by those for transportation and industrial sources derived by Miedema et al. (47, 48).

3.3.4 Influence of exposure (duration, intermittence, time of day)

The review did not identify any specific research directly examining the effects of duration and intermittence of AM in WTN exposure on responses in the field. However several studies have suggested that WTN AM is more likely to occur during the early morning, late evening and night-time periods (1, 49, 50, 51), and that WTN can be more noticeable and intrusive at night (3, 52).

3.3.5 Influence of other factors

Several studies demonstrate that other acoustical and non-acoustic factors can also be important in moderating annoyance responses to WTN, including the following: sensitivity to noise; turbine

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[9] Other Amplitude Modulation, defined in ref. (58) and interpreted in ref. (37) as "…*larger AM depth in lower frequency regions than Normal AM*".

[10] Data from Lee, S, et al., 2009 (26)

[11] Figure reproduced from von Hünerbein, S, et al., 2013 (29), with the permission of RenewableUK.

visibility; attitude to wind turbine aesthetics; attitude to wind turbines; land-use classification (urban/rural); economic involvement with wind energy developments; exposure to wind energy-related media; recognition and association of sound with wind turbines; physical and mental health (2, 3, 53, 54, 55).

3.3.6 Robustness of evidence

Some potential risks of bias in the evidence have already been highlighted. In general, the results from laboratory-based exposure-response studies are limited by small samples typically recruited from non-representative populations (e.g. university students and staff). The exposures are also very short, between 10s and 30s; while this may not significantly affect the ratings expected within the experimental setup, it may not represent the responses expected from those exposed within sensitive settings, for longer durations, and in which the expectation of cessation of the exposure (i.e. respite) may be uncertain.

The field studies on the other hand, involve exposed populations but carry risks of selection bias, especially where problematic situations involving WTN have developed. Typically they do not feature control cases for comparison. All the field studies identified are cross-sectional, preventing examination of changes in the measured responses over time. Very few field studies directly compare AM with scaled responses, which limits their usefulness to the aims of this research.

3.3.7 Discussion

The evidence outlined above shows that, of the acoustic factors contributing to perception of AM in WTN, the time-averaged overall level and modulation depth appear to be the most important and a combination of these parameters could be used to express the expected response relative to a signal without AM. In terms of the average person, this equivalence seems to be in the region of 2-5 dB, and the perception of AM for most people increases from around 2 dB depth in the level envelope. Modulation frequency in the context of large-scale wind turbines has a small effect. The effects of duration, frequency and timing of AM occurrence have not been widely studied, though it seems clear that reports of adverse impacts are increased during the night-time. This could be due to increased prevalence of AM occurrence, or heightened noise sensitivity in domestic environments. It seems quite plausible that a combination of these factors could be expected.

The evidence reviewed supports the proposed use of a penalty regime for AM in WTN. In the absence of an ideal case-controlled AM exposure-response field study, the laboratory results offer the best available evidence to inform a penalty planning control.

4. Proposed Planning Control

4.1 Planning Context

Current UK planning policy (56) requires any condition applied to pass ‘six tests’ for legal validity, which address the following requirements; a condition must be:

1. ***Necessary***: its entire scope must be required to make an otherwise unacceptable development acceptable;
2. ***Relevant to planning***: it must relate to specific objectives and the scope of permission;
3. ***Relevant to the development***: it must be justified by the specifics of the development alone;
4. ***Enforceable***: it must be possible to detect a breach, and for the applicant to remedy a breach;
5. ***Precise***: it must be clear what shall be done to establish compliance; and
6. ***Reasonable in all other respects***: it must not place unjustifiable or disproportionate burdens upon an applicant.

Policy also requires that ‘significant adverse’ impacts be avoided, while other adverse impacts should be mitigated and minimised.

The AM control has only been designed for use with new planning applications; applicability for use in Statutory Nuisance investigations on existing wind turbine sites, where the legal regime is different (and outside the research scope), has not been considered.

4.2 Key Elements

The recommended elements to form an AM penalty planning condition are shown in Figure 9.

The prevalence of unacceptable AM was not evaluated as part of this study, but it is believed that the likely occurrence cannot be reliably predicted at the planning stage with the current state of the art. It was concluded that the control would by necessity be instigated by complaints (i.e. a ‘reactive’ control).

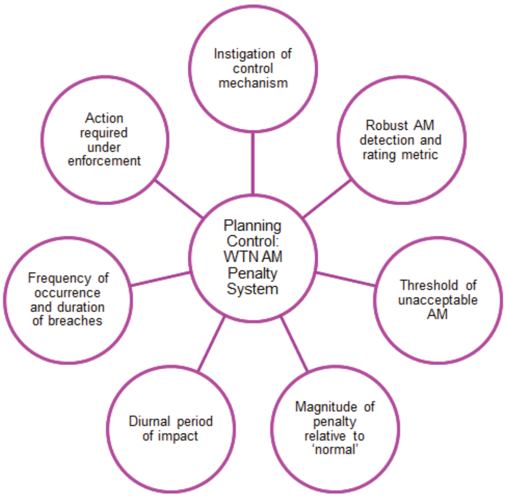

Figure 9 – Key elements to the planning condition

The IOA AMWG have conducted a review of existing approaches to rating AM, and developed a hybrid time and frequency-domain method that addresses shortcomings identified in alternative schemes. The output of this method is MD derived from a reconstructed filtered time-series of the original A-weighted envelope signal; this is compatible with the exposure-response research evidence, and is believed to be a robust approach to rating AM (14). The method is also based on 10-minute analysis periods, which makes it compatible with the existing ETSU-R-97 approach. Since AM is wind-speed dependant, the derived MDs would be separated by wind speed, enabling operators to identify the particular conditions leading to occurrences of high AM. It is noted that the IOA method is limited to a fundamental modulation (blade-pass) frequency of around 1.5 Hz, equivalent to 30 RPM for a 3-bladed turbine; this limitation means the proposed control addresses typical large-scale turbines but is not intended for smaller installations with higher rotation speeds.

The threshold and magnitude for an AM penalty have been derived from the evidence review, with the proviso that a 3 dB MD (just above the 2 dB threshold of perception) is considered normal within the existing ETSU-R-97 guidance; to avoid placing an unjustifiable burden on applicants (vis-à-vis the 'six tests') the proposed penalty starts at 3 dB MD. This is also supported by the evidence, which generally shows a relatively small difference in perception or response between 2 and 3 dB MD. The proposed regime is illustrated in Figure 10. The dB penalty is added arithmetically to the time-averaged level, similarly to the ETSU-R-97 approach to penalising tonality; the tonality and proposed AM penalties would be additive.

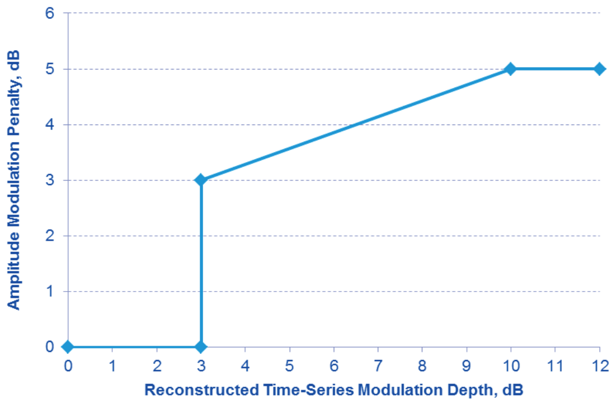

Figure 10 – Proposed AM level penalty regime

The review found that AM generates greatest adverse impacts during night-time or early morning periods. The ETSU-R-97 guidance includes a less stringent lower limit for the night-time (2300-0700hrs), which could have the result that a penalty added to the time-averaged level would result in a breach during the day, but not at night, when impact is expected to be increased. To address this discrepancy, it is proposed that for sites at which the night-time lower limit is less stringent, the difference between day and night limits would be added to the penalty, such that night-time periods would have sufficient protection for the impact of AM.

In view of the lack of identified evidence concerning the impact of occurrence frequency and duration of AM, it is proposed that this judgement is best addressed by the environmental protection officers investigating any complaints or alleged breaches; this approach is in line with the ways in which other forms of noise disturbance are currently handled in the UK. These judgements of impact would be informed by the number of 10-minute breaches detected, duration, time of day, sensitivity and so on. It is not envisaged that a single breach in any period would automatically trigger enforcement action; the expertise and experience of the officers will guide reasonable application.

The main purpose of the penalty is to bring about a reduction in the impact as a result of the period of unacceptable AM, and as currently proposed this consists of a two-tiered approach. The first tier would seek a reduction in the AM using engineering methods to reduce the AM to an acceptable degree of impact. Recent work (57) has indicated some of the potential measures available, such as blade treatment and programming modifications. Where the degree of AM (modulation depth, frequency of occurrence, etc.) cannot be reduced, the penalty should bring about a reduction in the overall level of WTN during periods of AM breach conditions (i.e. identified by wind speed and direction) such that overall limits are met, since this would also result in reduced impact from AM. It is envisaged that a reduction in overall level would be achieved by curtailment, i.e. reduced-noise operational modes and/or turbine shutdown.

Further research is recommended to supplement the limitations of the available research which underpins the above proposal, although if the proposed control successfully achieves the aim of reducing the impact from AM, then this research may not be required.

Given the gaps in current knowledge, the elements for the proposed control should be subject to a period of testing and review. The period should cover a number of sites where the control has been implemented, and would be typically in the order of 2-5 years from planning approval being granted.

5. CONCLUSIONS

WSP | Parsons Brinckerhoff has undertaken a review of research into the effects of and response to the acoustic character of wind turbine noise (WTN) known as Amplitude Modulation (AM). The objective was to evaluate the current evidence on the human response to AM, the factors that contribute to human response, and to make a recommendation to UK Government on how to decide what AM controls could be implemented through the planning system.

The work involved the collation and critical review of relevant papers, existing planning conditions, and existing planning policies where they relate to AM from wind turbines. The review established a need for AM control, a clear link between overall turbine noise level and annoyance, and a correlation between the degree of AM and an equivalent level without perceived AM. Based on the evidence found, a recommendation was made on the elements required to construct a planning condition to control AM. The review found that a planning condition should comprise the following:

1. It should be instigated by complaints about AM;
2. The IOA-developed rating metric should be used to quantify AM in 10-minute periods;
3. A level penalty should be imposed based on the modulation depth (MD) of detected AM; the threshold for which is 3 dB MD, and the penalty magnitude is a value between 3 and 5 dB over the range 3 to 10 dB MD;
4. The AM level penalty should be additional to any decibel penalty for tonality;
5. An additional decibel penalty is proposed during the night-time period to account for the current difference between the ETSU-R-97 night and day limits, to ensure the control method is effective during the night-time; and
6. Professional judgement should be used by statutory investigators to assess the impact of frequency and duration of any breaches identified, as for other types of noise source.

The elements for the proposed condition should be subject to a period of testing and review, covering a number of sites where the control has been implemented, in the order of 2-5 years from planning approval being granted. It is hoped that use of the control will lead to the development of more proactive approaches to prediction and mitigation of AM on the part of wind farm operators and developers.

ACKNOWLEDGEMENTS

This research was funded by the UK Department of Energy and Climate Change.

The authors are grateful for the contributions made to the study in the form of feedback from the

Steering Group, the IOA, the AMWG, Dr Frits van den Berg, Dr Sabine Janssen and Dr Jesper Hvass Schmidt.

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