A.45 The text accompanying the Table in the WHO Guidelines explains that the levels given in the Table are set at the lowest levels at which the onset of any adverse health due to exposure to noise has been identified. The text continues:

> *'These are essentially values for the onset of health effects from noise exposure. It would have been preferred to establish guidelines for exposure-response relationships. Such relationships would indicate the effects to be expected if standards were set above the WHO guideline values and would facilitate the setting of standards for sound pressure levels (noise immission standards)'.*

A.46 In addition to consideration of the absolute A-weighted level of a new specific source of noise, other properties of the noise can heighten its potential effects when introduced into an existing background noise environment. Such properties of noise are commonly referred to as 'acoustic features' or the 'acoustic character'. These acoustic features can set apart the new source of noise from naturally occurring sounds. Commonly encountered acoustic features associated with transport and machinery sources, for example, can include whistles, whines, thumps, impulses, regular or irregular modulations, high levels of low frequency sound, rumbling, etc.

A.47 Due to the potential of acoustic features to increase the effects of a noise over and above the effects that would result from an otherwise 'bland' broad band noise of the same A-weighted noise level, it is common practice to add a 'character correction' to the specific noise level before assessing its potential effects. The resulting character corrected specific noise level is often referred to as the 'rated' noise level. Such character corrections usually take the form of adding a number of decibels to the physically measured or calculated noise level of the specific source. Typical character corrections are around +5 dB(A), although the actual correction depends on the subjective significance of the particular feature being accounted for.

A.48 The objective identification and rating of acoustic features can introduce a requirement to analyse sound in greater detail than has thus far been discussed. To this point all discussion has focussed on the use of the overall A-weighted noise level. This single figure value is derived by summing together all the acoustic energy present in the signal across the entire audible spectrum from around 20 Hz to 20,000 Hz, albeit with the lower and higher frequency contributions down-weighted in accordance with the A-weighting filter characteristics to account for the reduced sensitivity of the human ear at these frequencies.

A.49 However, in order to identify the presence of tones (which are concentrations of acoustic energy over relatively small bands of frequency), or in order to identify excessive levels of low frequency noise, it may be necessary to determine the acoustic energy present in the noise signal across much smaller frequency bands. This is where the concept of octave band analysis, fractional (e.g. 1/3, 1/12, 1/24) octave band analysis, or even narrow band Fast Fourier Transform (FFT) analysis is introduced. The latter enables signals to be resolved in frequency bandwidths of down to 1 Hz or even less, thereby enabling tonal content to be more easily identified and measured. As standard, noise emission data for wind turbines is supplied as octave band data, with narrow band tests also being undertaken to establish the presence of any tones in the radiated noise spectrum.

Effects of Noise on Wildlife

A.50 There are large numbers of papers in the literature which describe the effects of noise on birds and animals, both wild and livestock.

A.51 Just as the assessment of noise effects on humans is made difficult by the variability of responses between different people and between different situations, assessment of noise effects on wildlife is even more problematical, not least due to the problem of monitoring the response of wildlife to noise.

A.52 For larger species, it may be possible to install telemetry on the body of the animal to relay information about its body systems (e.g. heart rate, temperature etc.). However, the minimum physical sizes of

telemetry systems means this is not an option for smaller species. Also, even where it is possible, the fact that the animals must first be captured to have a system installed disturbs them, and the results of the subsequent study may be biased. In the absence of such telemetric data, researchers must rely on observations such as flight from nests, short term departure from usually populated areas and deviations from expected line of travel. However, flock and pack instincts often mean that just one animal changing course or taking flight can result in all the others doing the same.

A.53 The only truly robust determinant to the effects of noise on wildlife is the long-term desertion of traditionally inhabited areas, or a reduction in breeding numbers. However, even these factors can be brought into question when the noise is a result of some other local activity, such as the passage of vehicles. In these cases, it is often difficult to establish whether the observed effect is a consequence of the visual disturbance or the noise.

A.54 Direct comparisons of results between species, or even between different research findings into the same species, are therefore often unclear, and it is difficult to draw firm conclusions as to the effects of noise on wildlife, other than in a highly generalised manner.

A.55 General features apparent from the literature are that the most sensitive time for animals is during nesting or breeding seasons. Those that take flight whilst sitting on their eggs or tending their young can leave them open to predators, even if they return fairly quickly. However, many species have been shown to habituate to noise of all types, including road traffic noise, aircraft noise or even the decreasing effectiveness with time of impulsive type bird scarers, such as those used around airports.

Low Frequency Noise and Vibration – Windfarms

A.56 One issue that has increasingly been raised concerning potential noise effects of operational windfarms relates not to the overall noise levels, but to the specific issue of low frequency sound. However, confusion sometimes arises from the use of the generalised term 'low frequency sound' to describe specific effects that may, or sometimes may not, actually relate the low frequency character of the sound itself.

A.57 In this respect, there are three distinct characteristics of sound that should be clearly differentiated between:

- Low frequency sound in the range from around 20 Hz to 200 Hz, which therefore lies within the commonly referenced range of human hearing of around 20 Hz to 20,000 Hz;
- Very low frequency sound, or infrasound, below 20 Hz, which therefore lies below the commonly referenced lower frequency limit of human hearing;
- Amplitude modulated sound that characterises the 'swish, swish' sound sometimes heard from rotating wind turbine blades.

A.58 Looking at the first two of the three types of sound referred to in the preceding bullet points, a distinction is usually made between low frequency sound and very low frequency sound, otherwise termed infrasound. This distinction is based on the fact that the frequency range of audible noise is generally taken to be from 20 Hz to 20,000 Hz. Therefore, the range of frequencies from about 20 Hz to 200 HZ is usually taken to cover audible low frequency sound, whereas frequencies below 20 Hz are usually described as infrasound. The implication here is that low frequency sound is audible and infrasound is inaudible. However, this relatively arbitrary distinction between low frequency sound and infrasound can introduce some confusion in that frequencies below 20 Hz can still be heard provided they produce a sound pressure level at the ear of the listener that lies above the threshold of audibility of that listener to sound at that particular frequency.

A.59 The fact that low frequency sound and infrasound from windfarms has only relatively recently been highlighted as a potential problem by some groups does not mean that that the wind energy industry had not previously considered the issue. In fact, the issue of low frequency sound was one of the predominant technical hurdles associated with the some of the earliest larger scale wind turbines installed in the USA. These turbines were of the 'downwind' type, 'downwind' referring here to the fact that the rotor blades were located downwind of the turbine tower rather than upwind of it, as is the case for current machines. It was found that the interruption of wind flow past the tower resulted in a region of lower than average wind speed immediately in the wake of the tower. The passage of the blades into this region of lower wind speed in the wake of the tower, then back into the higher wind speed as they emerged from the wake of the tower back into the main wind stream, resulted in the generation of low frequency sound, often in the subjective form of a distinctive impulse, often referred to as a 'thump' or 'tower thump'. It was for this reason that modern day turbine configurations now have the blades upwind of the tower, as research and measurements demonstrated that low frequency sound radiation is reduced to sub-audible levels once the interaction of downwind tower wake effects with the rotating blades are removed from the design.

A.60 One of the problems inherent in the assessment of both low frequency sound and infrasound is the variability of hearing sensitivity across human subjects with otherwise healthy hearing. This threshold for sound below 200 Hz varies significantly more between different subjects than does the hearing threshold at higher frequencies. However, what is always true is that the perception threshold to lower frequency noise is much higher than the perception threshold for speech frequencies between around 250 Hz to 4,000 Hz. For example, the average person with healthy hearing is some 70 dB less sensitive to sounds at 20 Hz than to sounds that fall within the range of speech frequencies. An additional factor relevant to the perception of infrasound is that, although audibility remains below 20 Hz, tonality is lost below 16 Hz to 18 Hz, thus losing a key element of perception.

A.61 Both low frequency sound and infrasound are generally present all around us in modern life. They may be generated by many natural sources, such as thunder, earthquakes, waves and wind. They may also be produced by machinery including household appliances such as washing machines and air conditioning units, all forms of transport and by turbulence. The presence of low frequency sound and infrasound in our everyday lives is heightened by the fact that the attenuation of sound in air is significantly lower at low frequencies than at the mid to high frequencies. As a result, noise which has travelled over long distances is normally biased towards the low frequencies. However, the fact that human hearing naturally down-weights, or filters out, sounds of such low frequencies means we are generally not aware of its presence. It is only under circumstances when it reaches a sufficiently high level, for example in the 'rumble' of distant thunder or the sound of large waves crashing on a shore, that we become aware of its presence.

A-Weighting

A.62 It is because the human ear increasingly filters out sounds of lower frequencies that environmental noise measurements are undertaken as standard using sound level meters that apply the A-weighting curve, as it filters out lower frequency sounds to the same degree as the hearing of a healthy person with unimpaired hearing. The A-weighted sound level is used as a measure of subjective perception of sound unless there exists such a predominance of low frequency sound or infrasound relative to the level of sound at higher frequencies that the use of the A-weighting curve would down-weight the actual source of the problem to such a degree that the resultant objective noise levels do not truly reflect the potential subjective effects of the noise. It is for this reason that a number of alternative weighting curves have been developed, specifically aimed at better accounting for the assessment of low frequency sound and infrasound.

C-Weighting

A.63 One such curve is denoted C-weighting. Unlike the A weighting curve, which gradually reduces the significance of frequencies below 1000 Hz until at 10 Hz the attenuation is 70 dB, the C-weighting curve is flat to within 1 dB down to about 50 Hz and then drops by 3 dB at 31.5 Hz and 14 dB at

10 Hz. The C weighting curve was originally developed to reflect the fact that, at higher overall noise levels, low frequencies can have a greater subjective effect than at lower overall noise levels.

A.64 One relatively simple measure of undertaking a first-pass assessment as to whether low frequency sound is likely to be an issue is to determine the difference between the overall C weighted noise level and the overall A weighted noise level. The C weighted level includes contributions from low frequency sound, whereas the A weighted level filters it out. It has been suggested in that a level difference of more than 20 dB indicates that low frequency sound may be subjectively significant, but more detailed investigations are in practice required to determine whether or not this is actually the case.

G-Weighting

A.65 Another curve, termed the G weighting curve, has been specifically derived to provide a measure of the audibility of infrasound when considered separately from higher frequency noise. The G weighting curve falls off rapidly above 20 Hz and below 20 Hz it follows assumed hearing contours with a slope of 12 dB per octave down to 2 Hz.

A.66 Over the past few years there has been considerable attention paid to the possibility that operational windfarms may radiate sufficiently high levels of infrasound to cause health problems. It has, however, been the case that dedicated research investigations have shown this not to be the case.

A.67 As early as 1997 a report by Snow [2] gave details of a comprehensive study of infrasound and low frequency sound (up to around 100 Hz) and vibration measurements made in the vicinity of a windfarm. Measurements were made both on the windfarm site, and at distances of up to 1 kilometre. During the experiments a wide range of wind speeds and directions were recorded. It was found that the vibration levels at 100 metres from the nearest turbine itself were a factor of 10 lower than those recommended for human exposure in the most critical buildings (i.e. laboratories for precision measurements), and lower again than the limits specified for residential premises. A similar comparison with recognised limits for assessing structural damage showed that the measured vibrations were a factor of 100 below the recommended guidelines at 100 metres from the turbines.

A.68 Noise and vibration levels were found to comply with recommended residential criteria even on the wind turbine site itself. Although low level infrasonic (i.e. below 20 Hz) periodic noise from the windfarm was detected by instrumentation at distances up to 1 kilometre, the measuring instruments used were much more sensitive than human hearing. Based on his measurements Snow concluded that subjective detection of the wind turbines may be apparent at this distance, but if this is the case it will be due to higher frequency components (which are more readily masked by general ambient environmental noise) and not the low frequency components which lie below the threshold of audibility.

A.69 In 2003, findings on both low frequency sound and infrasound have been compiled into the previously referenced extensive review report commissioned by DEFRA and prepared by Dr G Leventhall [1]. Dr Leventhall notes that despite the numerous published studies there is little or no agreement about the biological effects of infrasound or low frequency sound on human health. Leventhall notes that direct evidence of adverse effects of exposure to low-intensity levels of infrasound (less than 90 dB) is lacking. He goes on to describe the low frequency hearing threshold i.e. the lowest levels which are audible to an average person with normal hearing. He notes the threshold at 4 Hz is about 107 dB, at 10 Hz it is about 97 dB and at 20 Hz it is 79 dB. As such, high levels of infrasound are required to exceed the hearing thresholds at such low frequencies. Leventhall therefore concluded that most people can be reassured that there will be no serious consequences to peoples' health from infrasound exposure.

A.70 Indeed, specifically in relation to windfarms and infrasound, Leventhall went further still with his statement of reassurance. This additional reassurance followed the voicing of concerns by some interested parties that, because infrasound and very low frequency vibrations could be measured from windfarms, then it must follow that these were a potential hazard and source of annoyance. In fact what those concerned observers failed to account for is that highly sensitive electronic measuring equipment designed solely to detect such infrasonic sounds and vibrations is orders of magnitude more sensitive than even the most sensitive human. Thus, whilst such measurement systems may be able to detect such low-level phenomena, the same stimuli can have no effect on humans. In the light of this, Leventhall issued an open statement:

> *'I can state quite categorically that there is no significant infrasound from current designs of wind turbines. To say that there is an infrasound problem is one of the hares which objectors to windfarms like to run. There will not be any effects from infrasound from the turbines'.*

A.71 In 2004/2005 researchers from Keele University investigated the effects of the extremely low levels of vibration resulting from windfarms on the operation of a seismic array installed at Eskdalemuir in Scotland. This is one of the most sensitive ground-borne vibration detection stations in the world. The results of this study have frequently been misinterpreted, as just discussed for the DEFRA/Leventhall report, in that if infrasonic vibrations from windfarms can be measured, then they must consequentially have some potential effect on humans. In order to clarify their position, the authors have subsequently explained that [3]:

> *'The levels of vibration from wind turbines are so small that only the most sophisticated instrumentation and data processing can reveal their presence, and they are almost impossible to detect'.*

A.72 They then continue:

> *'Vibrations at this level and in this frequency range will be available from all kinds of sources such as traffic and background noise – they are not confined to wind turbines. To put the level of vibration into context, they are ground vibrations with amplitudes of about one millionth of a millimetre. There is no possibility of humans sensing the vibration and absolutely no risk to human health'.*

A.73 In relation to airborne infrasound as opposed to ground-borne vibrations, the researchers are equally robust in their conclusions, stating:

> *'The infrasound generated by wind turbines can only be detected by the most sensitive equipment, and again this is at levels far below that at which humans will detect low frequency sound. There is no scientific evidence to suggest that infrasound [at such an extremely low level] has an impact on human health'.*

A.74 Even more recently, in 2006, the results of a study specifically commissioned by the UK Department of Trade and industry (DTI) to look at the effects of infrasound and low frequency noise (LFN) arising from the operation of windfarms have been published in what is commonly referred to as the DTI LFN Report [4].

A.75 The DTI LFN Report is a comprehensive study containing many pages of detailed results of measurements of both infrasound and low frequency sound around the three windfarms included in the study. These measurements were undertaken using measurement systems capable of detecting noise down to frequencies of 1 Hz, with results being reported up to a frequency of 500 Hz, thus extending beyond the full spectrum of what is normally considered to cover both infrasound (<20 Hz) and low frequency sound (20 Hz to 200 Hz).

A.76 The measurement locations at the three windfarms were selected to be at residential properties where occupants had raised concerns relating to low frequency sound disturbance. Noise immission measurements are reported both externally to and internally to the properties in question. In addition to these noise immission measurements, the results of noise emission measurements undertaken on a

number of wind turbines are also reported with the aim of quantifying the level of infrasound actually emitted from individual wind turbines and windfarms.

A.77 Before summarising the findings of the DTI LFN Report, it is noted that the prevalence of the perceived problem of infrasound and/or low frequency sound is not a widespread one. Quoting from the Executive Summary to the DTI LFN Report:

> *'of the 126 wind farms operating in the UK, 5 have reports of low frequency sound problems which attract adverse comment concerning the noise. Therefore, such complaints are the exception rather than a general problem which exists for all wind farms'.*

A.78 The DTI LFN Report was actually commissioned primarily to investigate the effects of infrasound. This investigation was commissioned as a direct result of the claims made in the press concerning health problems arising from noise of such a low frequency 'that it is beyond the audible range, such that you can't hear it but you can feel it as a resonance'. For this reason the results pertaining to infrasound are reported separately from those pertaining to audible low frequency sound above 20 Hz.

A.79 In respect of infrasound, the DTI LFN Report is quite categorical in its findings: infrasound is not the perceived health threat suggested by some observers, nor should it even be considered a potential source of disturbance. Quoting from the Executive Summary to the DTI LFN Report:

> *'Infrasound noise emissions from wind turbines are significantly below the recognised threshold of perception for acoustic energy within this frequency range. Even assuming that the most sensitive members of the population have a hearing threshold which is 12 dB lower than the median hearing threshold, measured infrasound levels are well below this criterion.*
>
> *The document "Community Noise" prepared for the World Health Organisation, states that "there is no reliable evidence that infrasound below the hearing threshold produce physiological or psychological effects". Other detection mechanisms of infrasound only occur at levels well above the threshold of audibility.*
>
> *It may therefore be concluded that infrasound associated with modern wind turbines is not a source which will result in noise levels which may be injurious to the health of a wind farm neighbour'.*

A.80 In conclusion, whilst is known that infrasound can have an adverse effect on people (potential adverse health impacts are listed by the World Health Organisation as stress, irritation, unease, fatigue, headache, possible nausea and disturbed sleep), these effects can only come into play when the infrasound reaches a sufficiently high level. This is a level above the threshold of audibility. However, all available information from measurements on current wind turbines reveals that the level of infrasound emitted by these wind turbines lies below the threshold of human perception.

A.81 Indeed, in the face of the apparent misunderstanding of the conclusions reached in the various reports on infrasound, and how these conclusions should be applied to consideration of the radiation of such noise from wind farms, the British Wind Energy Association have issued a fact sheet relating to the subject [5]. This fact sheet concludes:

> *'With regard to effects of noise from wind turbines, the main effect depends on the listener's reaction to what they may hear. There are no direct health effects from noise at the level of noise generated by wind turbines. It has been repeatedly shown by measurements of wind turbine noise undertaken in the UK, Denmark, Germany and the USA over the past decade, and accepted by experienced noise professionals, that the levels of infrasonic noise and vibration radiated from modern, upwind configuration wind turbines are at a very low level; so low that they lie below the threshold of perception, even for those people who are particularly sensitive to such noise, and even on an actual wind turbine site'.*

Low Frequency Sound

A.82 A report prepared for DEFRA by Casella Stanger [6] lists windfarms as a possible source of audible low frequency sound (20 Hz to 200 Hz). However, this is one possible source in a list of many commonly encountered sources such as pumps, boilers, fans, road, sea and rail traffic, the wind, thunder, the sea, etc. The report only considers the general issues associated with low frequency sound and makes no attempt to quantify the potential problem associated with each of these sources. This is in contrast to other reports which have considered the specific situation associated with windfarms.

A.83 In respect of low frequency sound as opposed to infrasound, the DTI LFN Report identified that windfarm noise levels at the studied properties were, under certain conditions, measured at a level just above the threshold of audibility. The report therefore concluded that 'for a low frequency sensitive person, this may mean that low frequency sound associated with the operation of the three windfarms could be audible within a dwelling'. This conclusion was, however, placed into some context with the qualifying statement that 'at all measurement sites, low frequency sound associated with traffic movements along local roads has been found to be greater than that from the neighbouring windfarm'. In particular, it was concluded that, although measurable and under some conditions may be audible, levels of low frequency sound were below permitted night time low frequency sound criteria, including the latest UK criteria resulting from the 2003 DEFRA study into the effects of low frequency sound.

A.84 Based on the findings of the DTI LFN Report, low frequency sound in the greater than 20 Hz frequency range may, under some circumstances, be measured to be of a comparable or higher level than the threshold of audibility. On such occasions this low frequency sound may become audible to low frequency sensitive persons who may already be awake inside nearby properties, but not to the degree that it will cause awakenings. However, such noise should still be assessed for its potential subjective effects in the conventional manner in which environmental noise is generally assessed. In particular, the subjective effects of this audible low frequency sound should not be confused with the claimed adverse health effect arguments concerning infrasound which, in any event, have now been shown from the results of the DTI LFN Report to be wholly unsubstantiated.

A.85 In November 2006, the UK Government released a statement [7] concerning low frequency sound, reiterating the conclusion of the DTI LFN report that:

> *'there is no evidence of health effects arising from infrasound or low frequency sound generated by wind turbines'.*

A.86 The Government statement concluded the position regarding low frequency sound from windfarms with the definitive advice to all English Local Planning Authorities and the Planning Inspectorate that PPS22 and ETSU-R-97 should continue to be followed for the assessment of noise from windfarms.

Blade Swish (Amplitude Modulation)

A.87 The noise assessment methodology presented in ETSU-R-97, sets out noise limits which already account for typically encountered levels of blade swish. Notwithstanding the conclusions and advice presented in the preceding paragraphs concerning both infrasound and low frequency sound, the DTI LFN Report went on to suggest that, where complaints of noise at night had occurred, these had most likely resulted from an increased amplitude modulation of the blade passing noise, making the 'swish, swish, swish' sound (often referred to as 'blade swish') more prominent than normal. Whilst it was therefore acknowledged that this effect of enhanced amplitude modulation of blade aerodynamic noise may occur, it was also concluded that there were a number of factors that should be borne in mind when considering the importance to be placed on the issue when considering present and proposed windfarm installations:

- it appeared that the effect had only been reported as a problem at a very limited number of sites (the DTI report looked at the 3 out of 5 U.K. sites where it has been reported to be an issue out of the 126 onshore windfarms reported to be operational at the time in 2006);

- the effect occurred only under certain conditions at these sites (the DTI LFN Report was significantly delayed while those involved in taking the measurements waited for the situation to occur at each location);
- at one of the sites concerned it had been demonstrated that the effect can be reduced to an acceptable level by the introduction of a Noise Reduction Management System (NRMS) which controls the operation of the necessary turbines under the relevant wind conditions (this NRMS had to be switched off in order to gain the data necessary to inform the DTI LFN Report);
- whilst still under review, it appeared that the most likely cause of the increased amplitude modulation was related to an increase in the stability of the atmosphere during evening and night time periods, hence the increased occurrence of such an effect at these times, but this effect had been shown by measurement of wind speed profiles to be extremely site specific;
- internal noise levels were below all accepted night time criteria limits and insufficient to wake residents, it was only when woken by other sources of a higher level (such as local road traffic) that there were self-reported difficulties in returning to sleep.

A.88 The Government then commissioned an independent research project to further investigate the prevalence of the impact of enhanced levels of amplitude modulation across UK windfarms. This research work was awarded to the University of Salford who reported on their findings in July 2007 [8]. The Salford study concluded that that the occurrence of increased levels of 'blade swish' was infrequent, but suggested it would be useful to undertake further work to understand and assess this feature of wind turbine noise.

A.89 As a consequence of the findings of the report by the University of Salford, the UK Department for Business, Enterprise and Regulatory Reform (BERR formerly the DTI) issued a statement in August 2007 [9] which concluded:

> *'A comprehensive study by Salford University has concluded that the noise phenomenon known as aerodynamic modulation (AM) is not an issue for the UK's wind farm fleet.*
>
> *AM indicates aerodynamic noise from wind turbines that is greater than the normal degree of regular fluctuation of blade swoosh. It is sometimes described as sounding like a distant train or distant piling operation.*
>
> *The Government commissioned work assessed 133 operational wind projects across Britain and found that although the occurrence of AM cannot be fully predicted, the incidence of it from operational turbines is low'.*

A.90 The statement then concludes with the advice:

> *'Government continues to support the approach set out in Planning Policy Statement (PPS) 22 – Renewable Energy. This approach is for local planning authorities to "ensure that renewable energy developments have been located and designed in such a way to minimise increases in ambient noise levels", through the use of the 1997 report by ETSU to assess and rate noise from wind energy development'.*

A.91 This represents an aspect of wind turbine noise which has become the subject of considerable research in the UK and abroad in the past years and the state of knowledge on the subject is rapidly evolving. An extensive research programme entitled 'Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect' was published in 2013. This research, commissioned by RenewableUK (ReUK) was specifically aimed at identifying and explaining some of the key features of wind turbine AM noise.

A.92 Claims have emerged from different researchers that wind turbines were capable of generating noise with characteristics outwith that expected of them. This characteristic was an enhanced level of modulated aerodynamic noise that resulted in the blade swish becoming more impulsive in character, such that those exposed to it would describe it more as a 'whoomp' or 'thump' than a 'swish'. It could also become audible at distances from the wind turbines that were considerably greater than the distances at which blade swish could ordinarily be perceived. It has since emerged that this may be similar to the character of the noise identified in the DTI LFN study. Hence for the purposes of the ReUK project, any such AM phenomena with characteristics falling outside those expected of this "normal" AM (NAM) were therefore termed 'Other AM' (OAM).

A.93 The research identified the most likely cause of OAM noise is transient stall on the wind turbine blade (i.e. stall which occurs over a small area of each turbine blade in one part of the blade's rotation only). The occurrence of transient stall will be dependent on a combination of factors, including the air inflow conditions onto the individual blades, how these inflow conditions may vary across the rotor disc, the design of the wind turbine blades and the manner in which the wind turbine is operated. Variable inflow conditions may arise, for example, from any combination of wind shear, wind veer, yaw errors, turbine wake effects, topographic effects, large scale turbulence, etc. However, the occurrence of OAM on any particular site cannot be predicted at this stage.

A.94 As a consequence of the combined results of the ReUK research, and most notably the development of objective techniques for identifying and quantifying AM noise and the ability to relate such an objective measure to the subjective response to AM noise, ReUK has proposed an AM test [11] for implementation as a planning condition, although this was subject to discussion.

A.95 The Institute of Acoustics (IOA) published in 2016 a standardised methodology [12] for the assessment and rating of AM magnitude. The method provides a decibel level each 10 minute which represents the magnitude of the modulation in the noise, and minimises the influence of sources not related to wind turbines. The proposed method, unlike other methods that have previously been proposed, utilises as the core of its detection capability the fact that AM noise from wind turbines, by definition, exhibits periodicity at a rate that is directly related to the rotational speed of the source wind turbine. The IOA document does not however provide any thresholds or criteria methodology for using the resulting AM values.

A.96 The UK Government (DECC or Department of Energy and Climate Change, now obsolete) commissioned a review focused on the subjective response to AM with a view to recommend how this feature may be controlled. The outcome of this research has been published [13] in October 2016 by the Department for Business, Energy & Industrial Strategy (DBEIS). This report recommends the use of a "character penalty" approach, in which a correction is applied to the overall A-weighted noise level to account for AM in the noise in a manner similar to that used to assess tonality in the noise according to ETSU-R-97. This penalty is based on the above IOA methodology for detecting AM. The researchers make a number of recommendations for local authorities to consider and qualifications for the use of such controls, and note that the current state of knowledge on the subject and the implications of their proposed control is limited and that a period of testing and review over the next few years would be beneficial. The authors were however unable to provide clarity on how exactly the recommendations would operate in practice for any particular windfarm. On publication of the report, DBEIS encouraged local authorities in England to consider the research but provided limited guidance on how the outcomes were to be accounted for within the planning system. The Scottish Government is currently reviewing this report in the context of the Scottish planning system.

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Glossary of Acoustics Terminology

Terminology	Description
A-weighting	a filter that down-weights low frequency and high frequency sound to better represent the frequency response of the human ear when assessing the likely effects of noise on humans
acoustic character	one or more distinctive features of a sound (e.g. tones, whines, whistles, impulses) that set it apart from the background noise against which it is being judged, possibly leading to a greater subjective effect than the level of the sound alone might suggest
acoustic screening	the presence of a solid barrier (natural landform or manmade) between a source of sound and a receiver that interrupts the direct line of sight between the two, thus reducing the sound level at the receiver compared to that in the absence of the barrier
ambient noise	All-encompassing noise associated with a given environment, usually a composite of sounds from many sources both far and near, often with no particular sound being dominant
annoyance	a feeling of displeasure in this case evoked by noise
attenuation	the reduction in level of a sound between the source and a receiver due to any combination of effects including: distance, atmospheric absorption, acoustic screening, the presence of a building façade, etc.
audio frequency	any frequency of a sound wave that lies within the frequency limits of audibility of a healthy human ear, generally accepted as being from 20 Hz to 20,000 Hz
background noise	the noise level rarely fallen below in any given location over any given time period, often classed according to day time, evening or night time periods (for the majority of the population of the UK the lower limiting noise level is usually controlled by noise emanating from distant road, rail or air traffic)
dB	abbreviation for 'decibel'
dB(A)	abbreviation for the decibel level of a sound that has been A-weighted
decibel	the unit normally employed to measure the magnitude of sound
directivity	the property of a sound source that causes more sound to be radiated in one direction than another
equivalent continuous sound pressure level	the steady sound level which has the same energy as a time varying sound signal when averaged over the same time interval, T, denoted by $L_{Aeq,T}$
external noise level	the noise level, in decibels, measured outside a building
filter	a device for separating components of an acoustic signal on the basis of their frequencies
frequency	the number of acoustic pressure fluctuations per second occurring about the atmospheric mean pressure (also known as the 'pitch' of a sound)
frequency analysis	the analysis of a sound into its frequency components

Terminology	Description
ground effects	the modification of sound at a receiver location due to the interaction of the sound wave with the ground along its propagation path from source to receiver
hertz	the unit normally employed to measure the frequency of a sound, equal to cycles per second of acoustic pressure fluctuations about the atmospheric mean pressure
impulsive sound	a sound having all its energy concentrated in a very short time period
instantaneous sound pressure	at a given point in space and at a given instant in time, the difference between the instantaneous pressure and the mean atmospheric pressure
internal noise level	the noise level, in decibels, measured inside a building
L_{Aeq}	the abbreviation of the A-weighted equivalent continuous sound pressure level
L_{A10}	the abbreviation of the 10 percentile noise indicator, often used for the measurement of road traffic noise
L_{A90}	the abbreviation of the 90 percentile noise indicator, often used for the measurement of background noise
level	the general term used to describe a sound once it has been converted into decibels
loudness	the attribute of human auditory response in which sound may be ordered on a subjective scale that typically extends from barely audible to painfully loud
noise	physically: a regular and ordered oscillation of air molecules that travels away from the source of vibration and creates fluctuating positive and negative acoustic pressure above and below atmospheric pressure. Subjectively: sound that evokes a feeling of displeasure in the environment in which it is heard, and is therefore unwelcomed by the receiver
noise emission	the noise emitted by a source of sound
noise immission	the noise to which a receiver is exposed
noise nuisance	an unlawful interference with a person's use or enjoyment of land, or of some right over, or in connection with it
octave band frequency analysis	a frequency analysis using a filter that is an octave wide (the upper limit of the filter's frequency band is exactly twice that of its lower frequency limit)
percentile exceeded sound level	the noise level exceeded for n% of the time over a given time period, T, denoted by $L_{An,T}$
receiver	a person or property exposed to the noise being considered
residual noise	the ambient noise that remains in the absence of the specific noise whose effects are being assessed
sound	physically: a regular and ordered oscillation of air molecules that travels away from the source of vibration and creates fluctuating positive and negative acoustic pressure above and below atmospheric pressure

Terminology	Description
	subjectively: the sensation of hearing excited by the acoustic oscillations described above (see also 'noise')
sound level meter	an instrument for measuring sound pressure level
sound pressure amplitude	the root mean square of the amplitude of the acoustic pressure fluctuations in a sound wave around the atmospheric mean pressure, usually measured in Pascals (Pa)
sound pressure level	a measure of the sound pressure at a point, in decibels
sound power level	the total sound power radiated by a source, in decibels
spectrum	a description of the amplitude of a sound as a function of frequency
Standardised wind speed	Values of wind speed at hub height corrected to a standardised height of ten metres using the same procedure as used in wind turbine emission testing
threshold of hearing	the lowest amplitude sound capable of evoking the sensation of hearing in the average healthy human ear (0.00002 Pa)
tone	the concentration of acoustic energy into a very narrow frequency range

Annex B – Turbine Coordinates and terrain corrections

Table B1 – Development turbine coordinates

Turbine	Easting	Northing
1	219774	581117
2	219330	581708
3	218758	581958
4	217970	582203
5	218078	581522
6	218668	581153
7	218695	580330
8	219333	580621
9	219990	580339
10	219536	579827
11	219038	579261
12	219498	578843
13	220132	579054

Table B2- Propagation attenuation effects due to terrain (dB) – negative numbers (e.g. -3) corresponds to a negative attenuation and therefore represent an increase in noise, due to a concave ground profile. Where there is a zero shown, neither terrain shielding nor concave ground were found.

	Turbine number												
Property	1	2	3	4	5	6	7	8	9	10	11	12	13
Balkissock	2	2	2	0	2	2	2	2	2	2	2	2	2
Bellimore-on-Tig	0	0	0	0	0	0	0	0	0	0	0	0	0
Bents Farm	0	0	0	2	2	2	2	2	2	2	2	2	2
Brooklyn	2	2	2	2	2	2	2	2	2	2	2	2	2
Cairnlea	0	0	0	0	0	0	2	0	0	2	2	2	0
Chirmorie	0	0	0	0	0	0	0	0	0	0	0	0	0
Craigengells	2	2	2	2	2	2	2	2	2	2	2	2	2
Dochroyle Cottage	0	0	0	0	0	0	0	0	0	0	0	0	0
Dochroyle Farm	0	0	0	0	0	0	0	0	0	0	0	0	0
Duisk Lodge	2	0	2	2	2	2	2	2	2	2	2	2	2
East Altercannoch	0	0	0	0	0	0	0	0	0	0	0	0	0
Farden	2	2	2	2	2	2	2	2	2	2	2	2	2
Ferngate Cottage	0	0	0	2	0	0	0	0	0	0	0	0	0
Glenour	2	0	0	0	2	2	2	2	2	2	2	2	2
Gowlands	2	2	2	2	2	2	2	2	2	2	2	2	2
Gowlands Terrace	2	2	2	2	2	2	2	2	2	2	2	2	2
Kildonan Courtyard	2	2	2	2	2	2	2	2	2	2	2	2	2
Kilrenzie	0	0	0	0	0	0	0	0	0	0	0	0	0
Laggish	0	0	0	0	0	0	0	0	0	0	0	0	0
Laigh Altercannoch	0	0	2	2	2	2	2	2	2	2	2	2	2
Queensland Caravan Park	2	2	2	2	2	2	2	2	2	2	2	2	2
Scaurhead	2	0	2	2	2	2	2	2	2	2	2	2	2
The Craigs	0	2	2	2	2	2	2	2	2	2	2	0	0
The Manse	0	0	0	2	2	2	2	0	0	2	2	2	2
Ward of Cairnlea	2	2	2	2	2	2	2	2	2	2	2	2	2
West Altercannoch	0	0	0	0	0	0	0	0	0	0	0	0	0
Wheeb	0	0	0	0	0	0	0	0	0	0	0	0	0
White Cairn	0	0	0	2	2	2	2	0	0	2	2	2	2

Annex C – Noise Monitoring Information Sheets

Table C1 – Information on the measurement location, equipment and noise data at East Altercannoch.

Measurement Location Name	East Altercannoch
Measurement Location Description	The property is within a working farm located in the hills south-east of Barrhill. It was selected in preference to another farm (West Altercannoch) due to an increased level of tall vegetation at the latter. The sound level meter was installed in a garden area to the rear of the farm house as this was screened from most farm activities, more than 3 metres from the walls of the house, maximising distance from tall vegetation in the house particularly to the west. Audible noise at the house comprised mainly vegetation as well as some noise from farm activities and livestock. SLM Location: 223731 / 580935

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-52	00331833	15/08/2017
Pre-amplifier	Rion UC-59	04900	15/08/2017
Microphone	Rion NH-25	21784	15/08/2017
Calibrator	Rion NC-74	34172705	28/11/2017
SLM Range	20 – 110 dB(A)		

File	Time Start (GMT)	Time End (GMT)	Cal Start	Cal End	Drift	Notes
1	27/11/2018 15:00	04/12/2018 02:04	94.0	93.8	-0.2	No significant drift
2	13/12/2018 12:00	08/01/2019 12:40	94.0	94.0	0.0	No apparent drift

Data Exclusions
Periods 10 minutes before and after rainfall was detected were also removed (based on the rain gauge installed at Brooklyn).

Figure C1 View of the monitoring location at East Altercannoch looking north

Figure C2 View of the monitoring location at East Altercannoch looking south-east

Figure C3 View of the monitoring location at East Altercannoch looking west

Table C2 – Information on the measurement location, equipment and noise data at Brooklyn.

Measurement Location Name	Brooklyn
Measurement Location Description	The property is located on the south-eastern outskirts of Barrhill, amongst a group of similar detached houses. This particular property was chosen as it was relatively sheltered and had reduced levels of tall vegetation compared to other properties. The meter was installed in the rear garden of the property as this was also shielded from the traffic noise on the A714 to the north. Although a stream was present south of the property, the chosen location was in a lower location which was shielded from the stream noise by higher ground, and it was not clearly audible as a result. Audible sources of noise at the location mainly comprised wind in trees, as well as bird noise. SLM Location: 223711 / 581745

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-52	00832246	10/10/2017
Pre-amplifier	Rion UC-59	05473	10/10/2017
Microphone	Rion NH-25	32274	10/10/2017
Calibrator	Rion NC-74	34172705	28/11/2017
SLM Range	20 – 110 dB(A)		

File	Time Start (GMT)	Time End (GMT)	Cal Start	Cal End	Drift	Notes
1	27/11/2018 16:00	13/12/2018 12:10	94.0	93.9	-0.1	No significant drift
2	13/12/2018 12:40	07/01/2019 05:00	94.0	94.0	0.0	No apparent drift

Data Exclusions
Periods 10 minutes before and after rainfall was detected were also removed (based on the rain gauge installed at Brooklyn).

Figure C7 View of the monitoring location at Brooklyn looking south-west

Figure C8 View of the monitoring location at Brooklyn looking north

Figure C3 View of the monitoring location at Brooklyn looking south-east

Table C3 – Information on the measurement location, equipment and noise data at 4 Gowlands Terrace.

Measurement Location Name	4 Gowlands Terrace
Measurement Location Description	The property is one of a row of semi-detached houses in the centre of Barrhill. The sound level meter was installed in a rear garden location which was representative of other neighbouring residential locations, and not in excessive proximity to large vegetation in the area. The sound level meter was installed approximately 4 metres from the rear wall of the property. Noise sources include industrial activity from further east in the town as well as wind in vegetation. Intermittent road traffic was also audible. SLM Location: 223243 / 582217

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-31	00910453	14/03/2018
Pre-amplifier	Rion UC-53A	101799	14/03/2018
Microphone	Rion NH-21	02294	14/03/2018
Calibrator	Rion NC-74	34172705	28/11/2017
SLM Range	20 – 110 dB(A)		

File	Time Start (GMT)	Time End (GMT)	Cal Start	Cal End	Drift	Notes
1	27/11/2018 12:20	06/12/2018 07:20	94.0	93.8	-0.2	No significant drift
2	13/12/2018 14:00	31/12/2018 09:30	94.0	94.0	0.0	No apparent drift

Data Exclusions
Periods 10 minutes before and after rainfall was detected were also removed (based on the rain gauge installed at Brooklyn). In addition, the following periods were removed as atypical: during the quiet day-time, when L_{A90} noise levels were above 40 dB and wind speeds are below 7 m/s; at night-time, when L_{A90} noise levels were above 43 dB and wind speeds are below 10 m/s, or noise levels were above 50 dB below 11 m/s..

Figure C7 View of the monitoring location at 4 Gowlands Terrace looking south-east

Figure C8 View of the monitoring location at 4 Gowlands Terrace looking north-west

Figure C9 View of the monitoring location at 4 Gowlands Terrace looking north.

Table C4 – Information on the measurement location, equipment and noise data at Queensland Caravan Park.

Measurement Location Name	Queensland Caravan Park
Measurement Location Description	Queensland Caravan Park is one of two camping/caravan sites located on the western side of Barrhill, along the A714. A location at this caravan site was chosen in preference to the neighbouring Craigengells property (to the east) as the latter was surrounded by tall trees and a stream which dominated the background noise environment. By comparison, the chosen location, on the east side of the caravan site, had little tree cover and the stream was not clearly audible there. In addition to natural sources (mainly vegetation), intermittent traffic on the A714 was audible there. SLM Location: 221814 / 583389

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-32	01172484	12/06/2017
Pre-amplifier	Rion UC-53A	313611	12/06/2017
Microphone	Rion NH-21	25573	12/06/2017
Calibrator	Rion NC-74	34172705	28/11/2017
SLM Range	20 – 110 dB(A)		

File	Time Start (GMT)	Time End (GMT)	Cal Start	Cal End	Drift	Notes
1	28/11/2018 09:30	09/12/2018 19:50	94.0	93.9	-0.1	No significant drift
2	13/12/2018 15:10	30/12/2018 07:10	94.0	93.9	-0.1	No significant drift

Data Exclusions
Periods 10 minutes before and after rainfall was detected were also removed (based on the rain gauge installed at Brooklyn). In addition, the following periods were removed as atypical: during the night-time, when L_{A90} noise levels were above 40 dB and wind speeds are below 7.5 m/s.

Figure C10 View of the monitoring location at Queensland Caravan Park looking east