CD.SS 17.

Conjoined public inquiry concerning:

WIN 370-4 Craiginmoddie Wind Farm, Dailly, South Ayrshire, KA26.
WIN 370-5 Carrick Wind Farm, South of Straiton, South Ayrshire, KA19.
WIN 370-6 Knockcronal Wind Farm, Knockcronal, Straiton, South Ayrshire, KA19.

TOPIC : WIND TURBINE NOISE.

ON BEHALF OF Save Straiton for Scotland.

Core Document Save Straiton 17 Conditions Noise (Operational)

1. Save Straiton for Scotland propose much more robust Noise Conditions to be attached to any or all these applications, should they be consented.
2. It is not sufficient or appropriate to use a couple of tables of representative noise properties when such a large number of diverse properties are at risk. The conditions should relate to any property where noise becomes an issue and complaints are received.
3. **Requirements for Sound Monitoring for Operation Noise limits For all 3 Wind Power Plants WIN-370-4, 5 & 6 to protect residential amenity from adverse noise impacts.**

Purpose: To ensure there are unweighted recordings down to low frequencies. Monitoring the full spectrum of sound will provide all the data necessary for assessing AM and tonality.

Definitions

Measurement interval: The length of time for one, continuous sampling of sound, recorded as a series of 10–20-minute sound files.

Measurement Requirements

Requirement	Rationale
a) Measurements must be taken simultaneously inside and outside the residential dwelling.	ETSU states that the measurement must be taken no further away than 3.5m from the residence. Attenuation of the sound through the walls of the residence is predicted for audible frequencies but is significantly different for ILFN.

Requirement	Rationale
b) Measurements must sample all the significant wind directions and wind speeds of the annual wind rose of the area.	Winds measured over one period, of even several weeks, will often not include winds from all directions and wind speeds seen throughout the year.
c) Continuous sound recording must be made over the entire span of the measurement interval. Intervals should be at least one week in length. All the sound recordings must be made available to all interested parties through secured cloud storage.	Any independent investigator should have the original, raw data so that any analyses (existing and yet-to-be-developed) can be performed at any point in the future.
d) The sound must be recorded in uncompressed, 10–20-minute, WAVE files with at least 16-bit resolution and at least 44.1 kHz sampling frequency.	Providing recordings in proprietary formats does not allow independent investigators adequate access to the raw data needed for unrestricted analysis.
e) All frequencies of interest must be accurately recorded, from the lowest blade-pass frequency of any industrial wind turbines within 20 km of the recording site.	Industrial wind turbines generate frequencies down to at least their blade-pass frequency and cannot be fully analysed without including these.
f) Calibration tones must be recorded on the recordings at least once per week.	At any point in the future a calibration tone can be analysed to confirm calibration of the recording.
g) A GPS location and GPS-based timestamp must automatically be included in the metadata of each WAVE file at the time of recording.	The location of the recordings should not be in question but, of equal importance, the actual time, tied to the international GPS system, should be available, independent of the instrumentation clock.
h) A digital signature must be provided that can provide chain-of-evidence for the original recording and its metadata.	There should be a means for confirming that the recording was taken at the location and time stated in its metadata and that the data of the recording has not been altered since then.

4. Analysis

Analysis of the measurements should not be limited to audible or weighted acoustic parameters such as A-weighted measures, as these do not provide information on sound that is perceived through other than classical pathways. While the analysis of sound files of wind power stations is an evolving field some analyses can significantly improve the estimation of the effect wind turbines have on human perception and health.

The following requirements should be included in addition to those already proposed by acoustical standards.

1. Requirement	Rationale

1. **Requirement**	**Rationale**
a) Sonograms of unweighted sound from the blade-pass frequency, or below, to at least 1 kHz, with at least 1-second temporal and 1/36-octave frequency resolution for each sound file. (Or an FFT with resolution superior to the 1/36-octave resolution at the blade-pass frequency.)	Sonograms remain one of the most effective methods of visualising the character of sound and the presence of tonal components.
b) Harmonic analysis of each sound file to identify harmonic series from the blade-pass frequency to at least 0.3 times the highest frequency in the sonogram.	Harmonic series are very uncommon in nature and therefore usually have a man-made source. Wind Turbine Acoustic Signature is a harmonic series with the blade-pass frequency forming the fundamental. A method of determining harmonic series can be found in [CD SS12].
c) Calculation of the blade-pass harmonic prominence [CD SS12] for each sound file.	This measure provides a single parameter to estimate the effect of WTAS on humans. This is based upon the observations that impulsive sounds in the 'harbinger frequencies' can trigger the 'fight-or-flight' response in humans.
d) Blade-pass harmonic prominence should be presented in time-of-day plots covering each measurement interval. [CD SS 12]	These plots can provide an effective method of visualising when higher or lower levels of harmonic prominence are present at the residence.
e) Wind roses of harmonic prominence over all the measurement interval. [CD SS 12]	These wind roses can be used to visualise when higher or lower levels of harmonic prominence are present at the residence. Producing wind roses for various ranges of wind speeds can indicate which wind conditions produce high levels of harmonic prominence.

5. In CD SS5: paragraph 120:

The GPG also explains in section 7.1 that the guide cannot provide a definitive set of conditions for a wind farm, despite suggesting some options.

6. We refer to CD.SS5: ***Summary of Opinions*** paragraphs:

152 NSRs include at least one camping and caravanning site but this site and any other similar sites in the area have not been assessed.

153 The target noise limits from ETSU-R-97 are too high for an occupier of a tent or caravan to achieve undisturbed sleep. I suggest that the target noise limit for a camp site is 30 dB, LAeq (as per World Health Organisation recommendations) and that any such site must be evaluated accordingly in each assessment for the three wind farms.

6.1. Mr Huson Suggests:

NOISE SENSITIVE RECEIVERS (NSR)

Dwellings are generally considered to be NSR and the ETSU_R_97 night time noise limit of 43 dBA outside a dwelling assumes significant attenuation from outside a dwelling to inside a bedroom where it is assumed that a target noise limit of 30 dBA, Leq will be achieved to protect sleep (WHO Guidelines).

In the case of a camping ground it is impossible to achieve any significant attenuation of sound from outside a tent to inside where people sleep.

The target night time noise limit for camping areas should be set at 30 dBA, Leq, or 28 dBA, L90.

7. Suggested Condition to protect campers.

"Target noise limits outside any camp site area at night are determined as the base noise limit of 28 dBA, L90 or Background plus 5 dB, whichever is the greater, over the operating wind speeds of the chosen wind turbines."

This condition will protect the amenity of campers and prevent any adverse impact on tourism in the area.

8. We also reference CD.SS5: ***Summary of Opinions:***

    156 Excess amplitude modulation has been shown to be common near modern wind farms but prediction of this form of SAC is currently not possible. If the wind farms are permitted then a condition should be included in any Permit that provides an appropriate limit for amplitude modulation. Such a condition is already in force at the Denbrook Wind Farm as Condition 20 and this should be included for each of the proposed wind farms, and be renumbered appropriately.

CONDITION TO ASSESS AMPLITUDE MODULATION ACCEPTABILITY

STATIONARY ERGODIC DATA ANALYSIS

In signal processing and statistics, a stationary ergodic signal is a type of signal that satisfies two important properties: stationarity and ergodicity.

Stationarity refers to the property that statistical properties of the signal do not change over time. More specifically, a stationary signal has a constant mean, constant variance, and constant autocorrelation over time. In other words, the statistical properties of the signal do not depend on when the signal is observed.

Ergodicity refers to the property that the statistical properties of the signal can be estimated from a single realization of the signal. In other words, the average behaviour of the signal over time can be inferred from a finite-length sample of the signal.

Together, these properties make stationary ergodic signals useful for many applications in signal processing and statistics, such as modelling, filtering, and prediction. Examples of stationary ergodic signals include white noise, sinusoidal signals, and random processes with constant statistics over time.

8.1. Fourier analysis into and out of the frequency domain

The application of a Fast Fourier Transform (FFT) does not strictly require that the signal is stationary ergodic, but it is often assumed for practical reasons.

The FFT is a mathematical algorithm that is used to efficiently compute the discrete Fourier transform (DFT) of a signal. The DFT is a way to decompose a signal into its constituent frequency components. The FFT is commonly used in many signal processing applications, such as filtering, spectral analysis, and data compression.

In order to apply the FFT, the signal needs to be discrete and have a finite length. The signal does not necessarily need to be stationary ergodic, but it is often assumed to be so in order to simplify the analysis and interpretation of the results.

Assuming stationarity allows for the use of statistical measures such as the power spectral density (PSD), which describes the distribution of the signal's energy over frequency. The PSD is often used to identify dominant frequencies in the signal and to characterize the frequency content of the signal.

However, if the signal is not stationary, the use of the PSD can be misleading, as it may not accurately capture the time-varying nature of the signal. In such cases, alternative techniques such as time-sound level analysis may be more appropriate.

8.2. Errors associated with the FFT

FFT leakage, also known as spectral leakage or frequency leakage, is a phenomenon that occurs when the frequency components of a signal do not fall exactly on the FFT bin frequencies.

In the discrete Fourier transform (DFT), which is computed by the FFT algorithm, the frequency spectrum is represented by a finite set of discrete frequency components, or bins. Each bin corresponds to a particular frequency, and the amplitude and phase of each bin represent the magnitude and phase of the signal at that frequency.

However, when the frequency components of the signal do not fall exactly on the FFT bin frequencies, the energy of the signal can "leak" into adjacent bins, resulting in spectral leakage. This can cause distortion and errors in the frequency analysis of the signal, as the amplitudes of adjacent bins are affected.

Spectral leakage is caused by the windowing function applied to the signal before the FFT. The windowing function is used to reduce the effects of discontinuities at the beginning and end of the signal, but it also has the effect of spreading the frequency components of the signal over a range of frequencies, which can cause leakage.

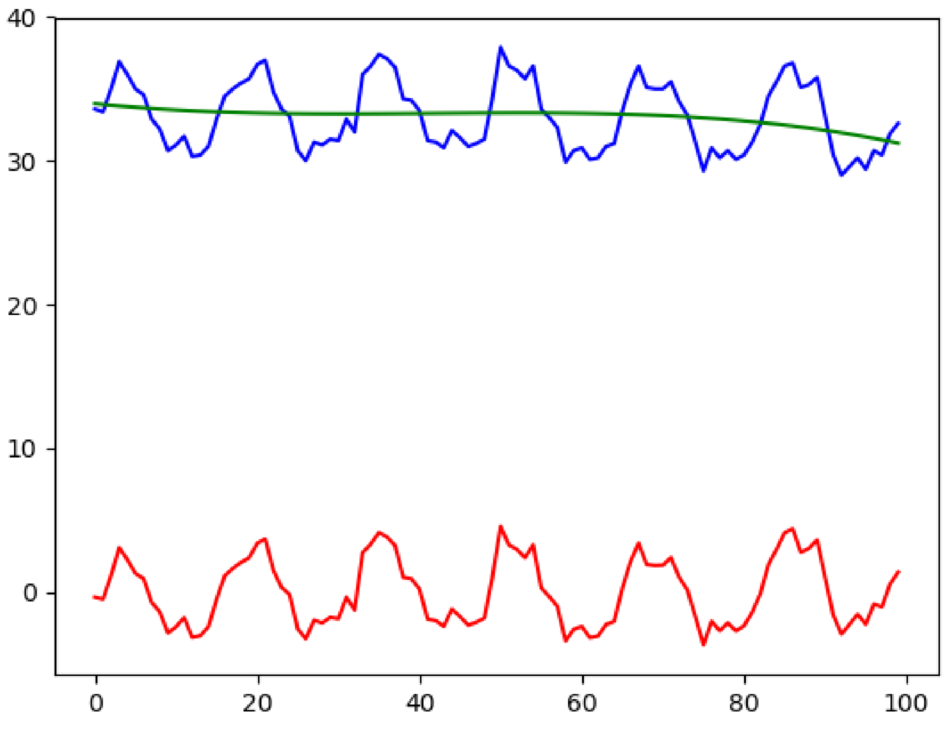
One way to reduce spectral leakage is to use a windowing function that has a narrow main lobe and low side lobes, such as the Hamming or Blackman-Harris window. Additionally, increasing the length of the FFT can help to reduce the spacing between the bins and improve the frequency resolution, which can also help to mitigate leakage.

8.3. Window functions

The basic 'window' of time that the IoA AM analysis uses is 10 seconds. A window function is often applied to a signal before applying a FFT such that the start and end of each window 10-second sample of amplitude modulated sound starts and ends at zero.

The IoA AM Method does not apply a window function to the signal before conversion into the frequency domain using an FFT. A 'Flat Top' or 'boxcar' window is effectively 'no window'. Instead, the IoA AM Method uses a third order polynomial offset to the signal (10-second long AM sound level sample).

The polynomial offset is required for each 10-second sample to minimise start and end transients and to offset the mean sound pressure level so that a signal is produced that oscillates around a zero value. The following chart shows an original 10-second recording in blue with the third order trend line in green that is applied to the blue line to get the offset signal in red that if then processed with a Fourier transform (FFT). The x-axis is time in units of 100ms and the y-axis is sound level in dB(A).



This third order polynomial offset does not completely remove transients at the start and end of each 10-second sample.

If you do not apply a window to a signal before performing an FFT, the discontinuities at the start and end of the sample can cause artefacts in the frequency domain, which can appear as spectral leakage or false frequency components. This effect is known as spectral leakage due to the end effects.

When you perform an FFT on a finite length signal, you are essentially assuming that the signal is periodic beyond the bounds of the window. However, because the signal is truncated at the edges of the window, it does not actually repeat perfectly, and there is a sudden jump at the beginning and end of the window.

This jump causes high-frequency components to be introduced into the frequency spectrum, which can be seen as false frequency components or noise in the frequency domain. This can make it difficult to accurately determine the true frequency content of the signal.

Applying a window function to the signal before performing the FFT helps to reduce these end effects by tapering the signal to zero at the edges, which smooths out the discontinuities and reduces the high-frequency components that are introduced. This helps to improve the accuracy and reliability of the frequency analysis. However, the IoA AM Method does not apply a window function.

8.4. Prominence and harmonic manipulation

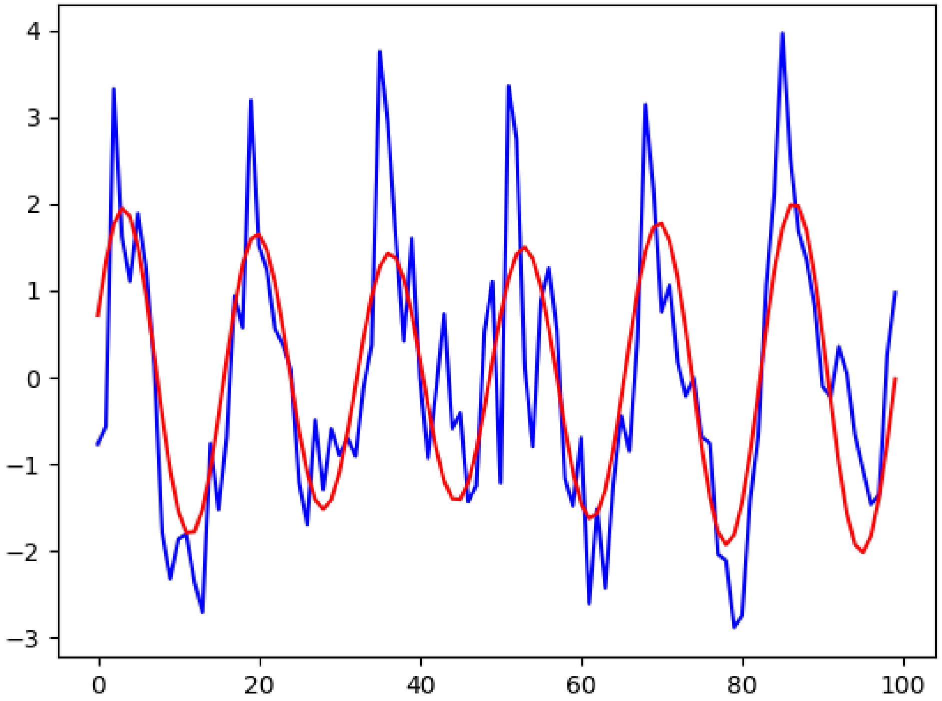
After a FFT is applied to the signal that has been offset there are a number of additional manipulations applied in the IoA Method that further diminish the original time signal that represents a 10-second sample observed outside a dwelling.

A Prominence test is applied to check if there are regular periodic variations in the recorded 10-second sound levels.

A further test is applied to allow or not allow the harmonics of any periodic signal to be included before an inverse FFT is performed to reconstitute a 10-second sound level trace, in red below.

The following chart shows what effect these manipulations can have on the recorded 10-second sound level data recorded 800m from two RePower 2MW wind turbines.

The recorded data contained only wind turbine sound and was unaffected by any extraneous noise.



In this chart the x-axis is again units of 100ms (10 seconds in total) and the y-axis is dB(A).

The blue trace is the recorded 10-second sound level data after applying the third order polynomial offset and the red trace is the result after manipulation by the IoA Method to recreate the original recorded data.

Clearly, the IoA Method greatly reduces the true amplitude modulation peak-to-trough value of the blue trace from approximately 5dB down to only 3dB. Each of the amplitude modulation peak-to-trough values are reduced by 2 dB and the detail of the original sound level trace (blue) is lost.

The charts shown above were derived using the Python code provided by the IoA.

Each 10-second data sample is assigned an AM value based upon the difference between the 5^{th} and 95^{th} centile (sound level L5 of the red trace minus the L95 of the red trace).

This further reduces the maximum peak-to-trough AM observed.

The cumulative 10-minute IoA AM Metric further diminishes the 60 individual10-second data samples by taking the 10^{th} centile (L10 of the 60 AM values obtained from each manipulated red trace).

Again, this process reduces the assigned dB value to a metric that greatly underestimates the true AM and furthermore ignores the occasional excessive AM commonly referred to as ‘whump’ or ‘thump’.

9. SUMMARY

Application of the IoA AM Method significantly underestimates the true amplitude modulation experienced at a dwelling.

The use of the IoA AM Method is not fit for purpose when assessing AM from more than one wind turbine.

The IoA Method could produce reasonable results if the recorded sound levels were stationary ergodic. This condition may arise when observing close to a single wind turbine in constant wind conditions.

However, multiple wind turbines that may contribute to amplitude modulation in practice produce sound level data that is not stationary ergodic and the IoA AM Method greatly underestimates the true AM that a person will observe at a dwelling in these situations.

A penalty determination using the IoA AM Method has been suggested by WSP (Review of the evidence on the response to amplitude modulation from wind turbines, WSP for Department for Business, Energy & Industrial Strategy, 2016). However, the proposed penalty scheme was not approved or adopted by the DBEIS and has been widely criticised by acoustic consultants in the UK.

In Scotland, a few wind farms have recently been given approval with a condition referencing the IoA AM Method. Unfortunately, this condition renders the assessment of AM useless for these wind farms. As a result, a permit condition that uses the IoA AM Method cannot provide an accurate description of the actual AM that a community is experiencing.

10. Alternative AM Condition

A better analysis method to use is the direct observation of sample sound level charts that does not require manipulations into and out of the frequency domain (FFT to InverseFFT).

Such an analysis method is described in Condition 20 of the development permit for the Den Brook Wind Farm, as follows:

"Condition 20
At the request of the local planning authority following receipt of a complaint the wind farm operator shall, at its expense, employ a consultant approved by the local planning authority, to assess whether noise immissions at the complainant's dwelling are characterised by greater than expected amplitude modulation. Amplitude modulation is the modulation of the level of broadband noise emitted by a turbine at blade passing frequency. These will be deemed greater than expected if the following characteristics apply:

> **(a) A change in the measured LAeq, 100 milliseconds turbine noise level of more than 3 dB (represented as a rise and fall in sound energy levels each of more than 3 dB) occurring within a 2 second period.**
> **(b) The change identified in (a) above shall not occur less than 5 times in any one minute period providing the LAeq, 1 minute turbine sound energy level for that minute is not below 28 dB.**
> **(c) The changes identified in (a) and (b) above shall not occur for fewer than 6 minutes in any hour.**

Noise immissions at the complainant's dwelling shall be measured not further than 35 m from the relevant building, and not closer than within 3.5 m of any reflecting building or surface, or within 1.2 m of the ground."

The Den Brook AM Condition was confirmed to be appropriate in a High Court judgement resulting from an appeal by the Developer (RES).
(http://www.bailii.org/ew/cases/EWCA/Civ/2011/638.html)

No equivalent High Court judicial review on the validity of any AM condition using the IoA AM Metric has been heard to date.

The Den Brook AM Condition 20 should be considered in preference to any AM penalty assessment that uses the IoA AM Metric.

The Den Brook Condition 20 does not assign a penalty to noise immissions measured using the ETSU-R-97 process. The condition simply states that a breach of the development permit arises if amplitude modulation is greater than expected after applying three simple tests.

The High Court decision explored the issue of AM extensively and the application of Condition 20. An ambiguity arose in what non-compliance with Condition 20 would trigger.

To obviate those concerns it would be useful to add to Condition 20 that:
"If greater than expected amplitude modulation is demonstrated then the wind farm operations must be curtailed such that greater than expected amplitude modulation does not occur at the complainant's dwelling"

In addition Mr Huson states:

For infrasound I suggest that a precautionary condition be included along the lines of;

"If ongoing research into adverse effects on health from wind farm generated infrasound demonstrate that there are target infrasound noise limits that protect health then those limits, if deemed appropriate by the UK Government will apply to this Permit."

I suggest DEFRA NAN-R45 limits indoors of NSR for low frequency noise (this would also apply inside a tent, caravan or yurt).