THE INFLUENCE OF METEOROLOGY ON THE PROPAGATION OF SOUND AND IT'S MEASUREMENT – AN OVERVIEW

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1 INTRODUCTION

A recent study[1] into the sources and magnitudes of uncertainty identified the weather and changes in the weather as being one of the most significant influences on measurement uncertainties affecting the generation, transmission and detection of environmental noise. That the weather affects noise transmission has been known for some considerable time. Early determinations of the speed of sound were affected by the weather[2] and there have been numerous attempts, recorded in the literature, to explain unexpected propagation phenomena that often accompanied reports of hearing sound from large explosions. h fact, there have been suggestions that battles have been lost based on a misunderstanding of long range sound propagation and the way it is influenced by the weather[3].

Most practitioners engaged in the measurement of noise will be familiar with the need to use a windshield on sound level meters especially when measuring outdoors. They will also be familiar with the basic concepts behind measuring microphones and the fact that they are designed to minimise effects induced by meteorological changes in temperature, humidity and pressure. Many will have experienced the frustration of being caught in a rainsquall and the urgent need to protect the equipment as a whole from excessive moisture. In the main acceptable measuring conditions are chosen for practical reasons which are not related to the limits of the instrumentation. In fact, there is probably a general acceptance that the instrumentation will cope. Very few practitioners will study the performance specifications, especially, for instance the influence of the chosen windshield on the free field frequency response or the influence of wet as opposed to dry windshields and apply appropriate corrections.

Why is this? Is it down to bad training or a perception that the changes are negligible when compared with other factors that influence the noise? Is it down to a perception that the instrument manufacturers job is to "look after" such matters? Perhaps it is a resignation that there is little that can be done in practice and that the best thing to do is to try to minimise the changes and accept a greater uncertainty in the measured result.

One possible reason for ignoring the relatively small influence of weather on the instrumentation is the realisation that the weather has far greater effect on the propagation or transmission of noise. Obtaining measurement conditions that minimise the effect of changes in wind velocity, air temperature and humidity is by far a greater challenge to the practitioner. In this respect, the standards which the practitioner uses to bring some consistency to the measurement procedure often include guidelines on how to minimise the effects of the weather on measurements. These include, often without going into detail, strong hints that the source of noise may also be influenced by the weather.

We have the three elements of any outdoor noise scenario potentially affected by the weather, the generation at source, the transmission path and the detector or receiver. In the present context, we can eliminate the effect on weather on the noise source by ensuring that the effect of changes in the weather on the character of the source are known and logged as the measurement is made. It is necessary to determine, for instance, whether extra compressors are running, whether cooling louvres are open or closed and particularly on a hot summer evening, whether the factory doors have been left open. The influence of the weather on the transmission path and on the receiver is less easy to determine.

2 THE EFFECT OF METEOROLOGY ON TRANSMISSION

Variation in the propagation conditions introduces the most important and difficult source of uncertainty to many environmental noise measurements. The difficulties arise from:

- Understanding how the various meteorological factors influence noise propagation
- Measuring the prevailing meteorological conditions over the propagation path for the duration of the measurement.

Meteorology affects noise propagation through two principle mechanisms:

- Refraction: The propagation path is changed from a straight line to a curve which can be either bent upwards away from the ground causing shadow zones or downwards towards the ground causing enhancement or even focussing of the sound.
- Atmospheric absorption: Due to molecular absorption the air acts as a low pass filter attenuating mid and high frequency sound with increasing distance from source.

Both mechanisms have more influence over longer paths and in most instances the affect of meteorology on sound propagation increases with source to receiver distance. However, the effect of meteorological variables on the propagation of sound has been noticed over distances as small as twenty-five meters[4]. For propagation close to the ground over distances of less than 100m, the effect of meteorology is generally small and can usually be ignored[5].

The net effect is complicated by the interaction and instability of each of the meteorological variables described below and it is essential to select carefully the conditions under which any environmental noise measurements are made. In general, noise levels tend to remain reasonably steady downwind of the source on days when the atmosphere is relatively stable and under such conditions, a general enhancement of the noise level takes place over a relatively wide arc. Small changes in wind direction are not usually critical. Upwind areas are usually in a sound shadow but the depth of the shadow will be determined mainly by the amount of turbulence that causes scattering of sound.

However meteorological changes can have a large effect on noise propagation and this is demonstrated especially with high noise level sources where the effects can be observed over long distances. The longer the distance, the greater is the influence of the weather.

2.1 Refraction

Briefly, the noise propagation is controlled by the rate of change of sound speed with altitude, which is mainly a function of the wind vector and temperature. Usually the wind vector has an influence an order of magnitude greater than temperature. When the wind is very light there is often a decrease of temperature (lapse) upward from the ground. This bends sound upward resulting in a sound shadow at all azimuths. However as the wind speed increases, friction at the surface causes the wind nearer the surface to have a lower velocity than that in the layer above creating a significant wind gradient up to several hundred metres altitude resulting in a sound speed increasing with height (positive gradient) downwind. This is easily sufficient to overcome the temperature lapse and produce an enhancement by bending the sound back to the ground. Upwind the effects of the temperature gradient are reinforced. In the presence of a low level temperature inversion, experienced on cold, windless, frosty mornings or at night when there is often a nocturnal temperature inversion of several hundred metres depth above the ground, sound is refracted back towards the ground giving sound enhancement in all directions. If any wind is present, it will result in there being a preferred direction for the enhancement. Above a few hundred metres' altitude, horizontal temperature gradients are the main cause of wind changes especially in the region near a weather front. Ahead of a warm front the winds increase and turn clockwise (veer) with height and to the rear of a cold front the winds increase and turn anti-clockwise (back) with height resulting in a change in wind direction of up to 180deg between the surface and 3000m. This can result in significant changes in the sound speed gradient that causes the sound to return to the ground at several kilometres from the source, often in a different direction to the surface wind. In addition, there is always a possibility that elevated inversions will occur in the area of frontal systems. These can be quite sharp and can considerably influence propagation by refracting sound back to the ground.

Noise measurements should only be performed when the weather conditions are representative of the particular situation under investigation. If complaints are made about noise occurring under particular weather situations, then the measurements should be made under conditions which replicate those particular situations. Long-term average measurements must be made during periods with different types of weather. Several attempts have been made to "classify" weather situations[6,7] and these classifications are quite useful when determining average weather patterns. They are often accompanied by statistical data on the rate of occurrence and season and time of day of occurrence. If the measurement sample is to be truly representative of a particular season or even a whole year then the weather patterns for the whole of that period must be taken into account.

In the absence of any information on the operation of the noise source which is specific to particular weather conditions it is recommended that measurements are carried out under reasonably stable meteorological conditions. This will improve reproducibility.

The most common stable condition for noise measurements occurs under downwind refraction when the noise levels usually decay uniformly with distance and remain reasonably steady over an extended period (provided the source remains steady). To meet these requirements the wind direction should remain within approximately ± 60° of the direction from the source (wind blowing from source to measurement position). The wind speed should be between 2m/s and 3m/s at 3m to 11m above ground and there should be no strong temperature gradients near the ground.

Strong winds will reduce temperature gradients by mixing up the layers of air. An indication of the influence of wind and temperature on propagation can sometimes be obtained by observing the plumes of smoke from chimneys. Smoke rising vertically and then turning to the horizontal suggests the presence of an inversion. Billowing of smoke suggests turbulent conditions (see below) and smoke rising vertically indicates no wind or being emitted horizontally indicates high wind velocities.

2.2 Absorption

Atmospheric absorption of sound depends on both temperature and humidity. Absorption is much greater at higher frequencies for any given humidity and temperature combination; however the higher the humidity and temperature the less the atmospheric absorption The absorption characteristic is susceptible to sudden changes e.g. directly after a rain shower. However, small changes in humidity are only important if measuring at relatively close range (<200m) and where high frequencies are dominant.

High frequencies propagate better in fog because of the high humidity. Fog is usually formed when warm moist air lies over a cold surface. The upper air is often cold and shadow zones can form

Snow can significantly affect ground absorption and modify the amount of absorption expected from shrubs and trees. Caution must be exercised when estimating the effect of snow on the ground. The impedance can be influenced by the presence of denser frozen layers within the snow cover and sometimes the presence of standing pools of water on the icy surface. The effect of the ground can be significantly altered after precipitation, as the presence of water tends to make the surface acoustically “hard” i.e. less absorbent.

2.3 Ambient Pressure, Turbulence and Rain

Pressure has little effect on propagation when compared to the other variables and can generally be ignored. Changes in atmospheric pressure can however influence the operation of the noise source and the measuring instrumentation.

Turbulence does not significantly absorb sound, but will scatter sound into regions, which might otherwise be acoustic shadows. Turbulence can be caused by the wind being forced around trees and buildings or by convection air currents generated on sunny days by the warming of the air near the ground surface. Turbulent conditions can be identified visually by the shimmering of distant objects by day or the twinkling of stars at night. On a larger scale, the presence of cumulus clouds and strong cloud plumes indicates regions of turbulent air.

Rain will affect humidity and its onset can herald a change in both temperature and wind velocity. Rainfall and hail can produce wide band noise that can significantly change the general background noise.

3 METEOROLOGICAL EFFECTS ON INSTRUMENTATION

In general it is not a good idea to subject instrumentation to the extremes of weather and in particular to sudden changes caused either naturally or artificially by, for instance moving equipment rapidly from a warm interior to a cool exterior. Certain parameters have significant effects on sound level meters and microphones.

3.1 Temperature and humidity

Thanks to good design based upon many years of experience by the manufacturers, the sensitivity of measurement microphones is only slightly affected by the ambient temperature. It is usually not necessary to compensate for this influence, unless the microphone is subjected to very high or very low temperatures, an unusual experience. Most sound level meters and their microphones are designed to be used in the temperature range –10°C to +50 °C, with only a ± 0.5dB variation in response. However following relatively quick changes in temperature the microphone should be allowed to acclimatise for at least 15 minutes at the ambient conditions to ensure correct operation[9]. Such a situation could occur if, for instance, equipment is left in a car during hot weather.

In general, humidity has no influence on the sensitivity and frequency response of the microphone. However, some microphones have a layer of quartz on the diaphragm which absorbs moisture. This leads to a decrease in tension of the diaphragm and a corresponding increase in microphone sensitivity. The magnitude of this effect is typically 0.4dB/100% relative humidity. Information that is more specific may be obtained from the manufacturer's data books. The situations where one should be aware of humidity problems are when sudden changes in temperature and humidity occur, for example, when going from a warm, humid environment to a cool air-conditioned building. The opposite situation is not so critical because any condensation that may occur will only affect the outside of the instrument. However, if condensation occurs, it will usually result in some electrical leakage particularly of the polarisation voltage (if active) which obviously will result in a malfunction of the microphone and preamplifier. Moisture has the effect of attenuating the sensitivity of the microphone and as a side effect, increasing the inherent noise level. Therefore, prolonged exposure of sound level meters to extreme levels of humidity, either high or low, should be avoided[8]

3.2 Ambient (static) pressure

Ambient air pressure affects air stiffness and air density, which partially determine the impedance of the cavity behind the diaphragm and therefore the microphone sensitivity. However this effect is small, a ±10% change in atmospheric pressure will result in a change of less than ±0.2dB. However when measuring high frequencies at very high altitudes such changes may be exaggerated and the manufactures' instructions should be consulted.

Microphones are normally constructed so that any static pressure difference that could occur across the diaphragm is eliminated by the use of a static vent tube. The dimensions of this tube usually control the low frequency response of the microphone. Microphones, which are designed for use at very low frequencies, have this static vent fully or partially blocked. If the microphone is subjected to a change in ambient pressure it usually takes some time for the pressure across the diaphragm to be equalised and this can cause erroneous readings. Changes in atmospheric pressure can affect the calibration level of calibration devices such as pistonphones and corrections will have to be made.

3.3 Wind Effects

Sound level meters should always be used with a windshield, not only because they reduce wind noise but also because they cushion the microphone from sharp impacts when measuring in the field. Even when measuring in gentle winds, strong gusts can induce noise despite the use of a windshield.

When measuring out of doors, wind induced noise can add to the noise level. This can be noise induced directly on the microphone or indirectly by inducing noise in trees, fences buildings and any other object that interferes with the airflow and causes eddying and turbulence. Wind noise induced directly at the microphone can be reduced by moving the source of disturbance away from the sensing element and there are a number of devices, so called windshields, that do this. The further the disturbance is from the microphone, the lower the induced noise level but there are practical physical limits to the design. Early windshields were cylindrical in shape and rather large. They had a wire cage over which was stretched a cloth with a low resistance to airflow. The microphone was located at the centre. Later designs used a streamlined shape to better deal with higher wind speeds but many applications especially permanent or semi-permanent installations do not have a preferred wind direction and for ease of use most windshields are either circular or cylindrical with as circular top[9]. Cloth has been replaced by foam which is resistant to humid and corrosive atmospheres and which is cheap to produce and replaced if damaged. A damaged shield can cause additional turbulence and noise.
The windshield will act as an acoustic filter and alter the apparent frequency response of the microphone. Some sound level meters include corrective filters that partially equalise this effect. The total change to the fequency response of the system will be dependent upon the design and age of the windshield but is usually greater the higher the frequency. For standard windshields, provided by the manufacturer, it will normally be small (typically less than 1dB at any one frequency over the range 10-10K Hz) and so would rarely merit detailed consideration in the context of field measurement. Manufacturers provide data in the form of free field correction curves[8].

A windshield of 10cm diameter should suppress wind noise by approximately 12dB or more; this is dependent on exact size and construction. The size of foam windshield is a trade off between a reduction in wind noise and the insertion loss through the foam. Larger windshields will attenuate more wind noise but also more of the acoustic signal.

Water loading of foam windshields can further change the overall frequency response of the measuring system depending on the type of windshield and amount of water. It has been observed that wet windshields can attenuate sound over the range 1.5–12 kHz and amplify frequencies above 12kHz. This effect may distort the acoustic signal by up to 2.5 dB for wet windshields and up to 4dB for water-saturated windshields[10].

Deterioration of windshields by UV degradation or by contamination with dust can alter the porosity affecting both wind reduction performance and frequency response. Degradation of the surface can induce eddying in wind and cause an increase in noise level.

When using permanent or semi-permanent installations to measure noise outdoors it is normal to use rain covers and bird spikes to protect the microphone. However when using a rain cover it is usually necessary to mount the microphone with the diaphragm facing vertically upwards. Under such conditions and depending on the nature and source of the noise to be measured because of the directional characteristics it may be more appropriate to use to use a pressure microphone instead of the usual free field microphone.

4 METEOROLOGICAL MEASUREMENTS

To assist in the interpretation of the results of any acoustic measurements some form of meteorological measurements should be made. The normal procedure is to obtain the local forecast from the meteorological office or equivalent and to supplement this by on site measurements. The minimum would be the periodic use of a hand held anemometer coupled with an estimate of wind direction. For more convenient and permanent logging instrumentation companies now offer a compact package which will provide wind vector, temperature, humidity and pressure in a form suitable for recording in the memory of a logging sound level meter. This instrumentation would normally be mounted on a separate tripod at 2m above ground. There are of course some rules to follow regarding positioning of the instrumentation to avoid particularly the effect of nearby obstacles, the usual rule of thumb being 10m away for every 1m above ground level. There is however little guidance available, if any, on whether the meteorological instrumentation should be located near the receiver or somewhere along the propagation path. It should be clear from the earlier commentary that some doubt should be placed on the value of a set of measurements taken at one position, particularly so if the transmission path is long. There is also a question on at what heights the measurements should be made.

Without detailed meteorological data, and sophisticated interpretation, it is difficult to assess the influence of the weather on any particular situation. There are a growing number of sound propagation prediction programs now available but they all have limitations. Although primarily aimed at calculating the noise distribution either down a line or over an area the models could be used in a "what if" mode so that the effect of both small and large changes can be studied. The more sophisticated models are quite capable, provided the appropriate meteorological data is available, of providing useful data to assist with the deployment of measuring equipment and subsequent analysis of the data. Currently these models require sound speed profiles up to several hundreds of metres and this data are generally available only at selected radiosonde stations. The Meteorological office can interpret such data and couple it with more detailed ground based data close to the area of measurements to provide a good estimate of the weather profile with height in that area.

To use these models successfully a knowledge of the sound speed gradient at the measurement site is required and this requires data, especially wind vector and temperature, at various heights especially in the lower few hundred metres. Currently such data can be obtained from a number of sources such as (1) on-site upper air data from radiosonde profiles; (2) meteorological mesoscale model data, forecast hourly, specific profiles are available for defined U.K. sites; (3) on-site surface based data for use in synthetic profiles constructed using boundary layer theory.

The latter provide reasonable predictions in downwind enhancement and upwind shadow regions but they are unable to represent elevated wind shear and/or inversions and will never predict focussing conditions.

The former requires balloon tracking, either using free pilot balloons or radiosonde balloons with radar reflectors. Tracking can be achieved by radar, by navaid systems such as Loran-C, by radio direction finding or by interfereometry. Of these radar provides the most accurate and most reliable method and is currently used by the meteorological office.

Two devices are available which can provide data from the lower atmosphere to assist with the determination of the sound speed profile, potentially in real time. They are remote sensing devices that allow continuous monitoring and hence produce regularly updated profiles. The first device is the SODAR (Sonic Detection and Ranging) which measures wind speed by detecting sound waves which are back scattered from the temperature structure and wind turbulence in the atmosphere. The second device is the LIDAR (Light Detection and Ranging) which detects the weak returns of light energy back scattered by atmospheric aerosols such as dust and smoke, which are agitated by temperature and wind turbulence in the atmosphere. Both use Doppler techniques to determine wind velocity. The LIDAR is a relatively recent invention and there is still some way to go before it can be put to anything other than experimental use. SODAR has now been around for some 30 years and recent developments have resulted in smaller, more mobile and hence more practical units coming onto the market. There is still a requirement for an instrument capable of fast detection of temperature structure in the lower atmosphere. Tethered balloons and meteorological towers, which can carry conventional sensors, are too limited to be of general practical use. There are potential developments to both SODAR and LIDAR that could allow their use for temperature profiling.

A reasonable "rule of thumb" to determine the height to which the meteorological data is required is " one unit up for every ten units out", i.e. 100m height for each 1km along the ground from source. However often neither the meteorological data nor its interpretation are generally available and due to the considerable influence of meteorology on sound propagation this fact must be realised and acted upon if significant uncertainties are to be reduced.

5 CURRENT GUIDANCE

Guidance on environmental noise measurement practice such as that contained in BS4142[11] has, with successive versions, concentrated on ensuring that the effects of the weather are properly considered. The committee drafts of the current revision of ISO1996 contain a significant amount of detail including an appendix covering meteorological windows (meteo window) and uncertainty.

BS4142 describes a number of precautions that have to be taken to "minimise the influence on the readings from sources of interference " and lists amongst others "wind, passing over the diaphragm...", "heavy rain, falling on the microphone windshield or nearby surfaces....." and it clearly states "use an effective windshield to minimise turbulence at the microphone". On the actual weather conditions under which measurements can be made, it requests that "...the measurement time interval is sufficient to obtain a representative value of the background noise level". It then goes on to explain that "background noise can be significantly affected by meteorological conditions, particularly where the main background noises are remote from the assessment location". It also states that "more than one assessment may be appropriate". Under "Information to be reported" it requires wind speed and direction, presence of conditions likely to lead to temperature inversion (e.g. calm nights with little cloud cover), precipitation and fog. It does not however give specific guidance on what conditions are the most appropriate to measure under.

The proposed revision of ISO 1996 provides more specific guidance. Part 1[12] warns "meteorological conditions may influence the received sound level if the distance between source and receiver is about 30m or more". In such cases it requires that noise limits shall be based on an average value for either all relevant

Part 2[13] goes much further and defines a "meteo-window" which is a set of weather conditions during which measurements can be performed with limited and known variation in measurement results due to weather variation. It goes on to define the conditions for modest conditions which require no monitoring of meteorological conditions and other conditions such as "favourable downwind" which require monitoring or "upwind" conditions that should be avoided. Part 2 also recommends that further guidelines be obtained from ISO 9613-2[14]. There is also some guidance on equipment use and the usual requirements for reporting the weather conditions at the time of the measurement.

6 CONCLUSIONS

From the above it can be concluded that the weather can have considerable influence on noise measurements. It is also unlikely that a full understanding of the effects of the weather on sound transmission or the ability to determine all relevant weather parameters with ease will be immediately forthcoming. Until they are, to reduce uncertainties in environmental noise measurements it is recommended that weather forecasts be used when planning measurement sessions and meteorological conditions recorded for the duration of the measurement and the observations reported. For long term averages the statistical spread of weather classes should be determined and measurement sessions planned accordingly. Measuring during extreme conditions should be avoided and unless specific conditions are required measurements should only be made during favourable propagation conditions.

7 REFERENCES

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