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SOUND PROPAGATION FROM HIGH POWER SOURCES OUT OF DOORS

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1. INTRODUCTION

The operation of high power impulsive sound sources such as explosives and gunfire, or high power continuous sound sources such as jet engines, industrial plant and loudspeakers arrays at pop concerts has often given rise to complaints from local residents about excessive noise. Many of these complaints are understandable given the size of the source and the location of the complainant and can be substantiated (although perhaps not to the satisfaction of the owners of the noise source!). Some appear difficult to substantiate particularly when they come from locations several kilometres from the source. Many of these instances can be explained through the application of the physical processes which control sound propagation in the atmosphere, particularly the effect of the weather. Predicting this effect is now possible given the power of relatively small computers.

The Department of Applied Acoustics has for a number of years been investigating the propagation of explosive noise around firing ranges. The object is to provide the Ministry of Defence with a means for controlling such noise to limit the exposure of personnel on the range and to limit the environmental impact in the surrounding area. This work has been supported by MoD Directorate of Defence Health and Safety and has been carried out in co-operation with the Meteorological Office.

The purpose of this tutorial paper is to outline the physical processes that have been investigated particularly regarding the meteorology and to consider which if, any are, useful in explaining noise propagation from more continuous sources such as loudspeaker arrays at pop concerts.

2. NOISE SOURCE

The first item to consider is the noise source itself. An explosive is effectively a point source with the sound propagating equally in all directions, assuming that it is suspended in free air and in a still atmosphere and also neglecting the non-linear effects which occur close to the source but which can and do influence propagation. The energy associated with such a source is distributed across a wide bandwidth. In the absence of any reflecting surfaces the noise level will follow the inverse square law and reduce at 6dB per doubling of distance from the source.

A loudspeaker array acts more like a plane source and it tends to have some directionality particularly at mid to high frequencies. The energy associated with the reproduction of pop music is also distributed across a wide bandwidth. In the absence of a reflecting surface there will be little attenuation immediately in front of the array and the inverse square law will only apply from a distance about ten times the array's largest dimension.

3. ATTENUATION OF SOUND IN STILL AIR

One factor which influences sound propagation in air is absorption by vibrational relaxation of the molecules principally oxygen and water vapour. More recent work has shown that other relaxational processes also occur in dry air and a small nitrogen/water vapour effect extends the frequency range of the absorption process to below 1kHz (fig 1). However below approximately 300Hz the attenuation is less than 2 dB/km.

The effect of relative humidity on attenuation is well documented and it is clear that the higher frequencies attenuate rapidly over relatively short distances.

4. GROUND EFFECT

This is primarily an interference effect between the direct wave from the source to the receiver and the indirect wave reflected at the ground. The nature of the reflection is influenced by the impedance of the ground. If the ground is acoustically "hard" then the reflection is specular and the reflected wave emanates from a point image. If the ground is acoustically "soft" then the image is considered "distributed" and to fully describe the phenomenon mathematically a "ground wave" term is needed.(fig 3)

Curves (fig 2) showing the above effect are characterised by the "ground dip" where there is a large increase in excess attenuation when source and receiver are separated by a large distance but are close to the ground.(The frequency at which the dip occurs increases as the difference between the direct and reflected paths diminishes.)
Research covering the above parameters is summarised in a paper by Embleton et al [1].

5. BARRIERS & TOPOGRAPHY

Close to the source or indeed close to the receiver barriers or screens can reduce noise levels, the amount of reduction being limited by the noise passing over the top or around the sides. At high frequencies barriers produce an acoustic shadow. As the frequency is reduced so diffraction of the sound occurs at the edges, the shadow region is filled and the barrier becomes ineffective.

The reduction due to a barrier can be calculated using the method of Maekawa [2]. If the barrier is narrow then the proportion of sound getting around the sides can be calculated and added to that getting over the top.

In a still atmosphere simple topographical feature can be modelled using Maekawa's method. In a moving atmosphere account has to be taken of the fact that the topography usually influences the local meteorology. It is first necessary to adjust the meteorology and then apply the topographical corrections. Techniques are only just being developed to do this.

A particular form of barrier often found at pop concerts held in stadia are the stands. These are often relatively complex structures and the effective sizes of the acoustic barrier have to determined after careful consideration of the geometry. In addition it should be noted that multiple reflections occurring within a stadium from the stand walls and roofs can result in some reverberant build-up which effectively increases the source noise level.

6. METEOROLOGICAL EFFECTS

The important parameter to consider is the speed of sound gradient which at any point in the atmosphere is influenced by the temperature and/or the wind vector.

In a standard acoustic atmosphere ie one where the speed of sound gradient is zero, sound radiates uniformly in all directions from the source. Using a ray analogy, the sound rays radiate from the source in straight lines. This situation can occur if the temperature remains constant with height and it is completely calm, which is very rare, or it can occur in a particular direction where the speed of sound gradient due to the temperature is matched by that due to an opposing wind gradient.

Normally there is a lapse of temperature from the surface and in the absence of any wind the sound speed will decrease with height and sound rays will be refracted upwards producing a sound shadow zone around the source. Under temperature inversion conditions the speed of sound increases with height and the sound rays are refracted downward producing a sound enhancement zone. Under certain conditions both effects can be present and in the particular case of an inversion above a normal lapse the rays can be brought back to a focus at the ground.

Wind being a vector quantity can produce a speed of sound gradient along a particular azimuth by varying in either speed or direction with height. In a simple case of vertical wind shear where the winds aloft are greater than near the ground the sound rays are bent downwards , downwind and upwards, upwind resulting in the well known effect that sounds are usually heard more loudly downwind and not at all upwind.

OUTDOOR SOUND PROPAGATION

In practice profiles of temperature, wind speed and direction are required to construct the sound speed profile for each azimuth. The magnitudes of the temperature and wind effects are not the same however. The temperature gradient can vary from about -1°C per 100m to about +10°C per 100m, equivalent to a speed of sound change from -0.6m/s to +6m/s. The wind speed change can reach ± 5m/s but typically the effect of the wind is an order of magnitude greater than that of the temperature.

On most days there is a lapse of temperature from the surface giving rise to a sound shadow zone at all azimuths provided the winds remain very light or calm. Due to the friction effects of the earth's surface, given anything but a very light wind, there will exist a significant gradient between the surface and 600m where the wind is not affected by surface friction. This results in positive sound speed gradient downwind and a negative one upwind. The former is sufficient to overcome the effects of the lapse rate and the sound rays are bent back towards the ground to produce an enhancement zone. The latter reinforces the shadow effect upwind.

Above about 600m wind changes are due to horizontal gradients of temperature and these are particularly strong in the vicinity of fronts, the boundary between warm and cold air masses. Ahead of a warm front the winds increase and veer with height and to the rear of a cold front the winds increase and back with height resulting in a change in wind direction of up to 180° from the surface to 3000m. Such influences on the speed of sound gradient can bring the sound rays back together at the ground at large distances from the source (10km to 20km) often in directions considerably different from the surface wind.

These effects are mainly responsible for the reports of "anomalous propagation" which have, in the past been put down to cloud reflections or temperature inversions.

7. CATEGORISATION OF METEOROLOGICAL CONDITIONS

It is convenient when running computer models of sound propagation in the atmosphere to categorise meteorological conditions. This has been done to speed up the response time and for one model currently under test six categories have been set up to cover most of the conditions we expect to encounter in practice.

Category 1 - is the normal lapse from the surface producing a negative sound speed gradient and a shadow region. If the source is located above the ground then some sound is radiated down to the ground but the upward refraction will produce a caustic.(fig 4)

Category 2 - is the surface inversion producing a positive sound speed gradient which results in sound energy being returned to the ground at all points along a radial.(fig 5)

Category 3 - an inversion below lapse. All rays which turnover below the "knee-point" return to the ground suffering downward refraction but all the rays which do not turnover are turned away from the ground suffering upward refraction. This is a very common condition.(fig 6)

Category 4 - Lapse below inversion. The lapse turns all the rays from the source away from the ground. When they reach the "knee-point" the inversion refracts them back down to the ground thus producing a large sound shadow extending from near the source to a distance depending on the height of the bottom of the inversion. At this point the returning rays produce a small region of high sound level.(fig 7)

Category 6 - Lapse-inversion-lapse. This is similar to category 4 where a shadow is followed by a region of high sound level. It is possible for some rays to get trapped between the two lapses suffering upward and downward refraction alternately. They can then travel some distance in this atmospheric waveguide. This phenomenon could be responsible for some of the reports on anomalous propagation.(fig 8)

Category 7 - Inversion-lapse-inversion. This condition produces a region of enhancement close to the source followed by a large shadow zone with strong ray returns at a very large distance from the source.(fig 9)

Identical sound speed behaviour can be produced by wind speed gradients and temperature gradients and many of the practical situations falling into the categories above are a result of a combination of both types.(Note Category 5 has been reclassified to 4 or 7.)

8. MODELLING SOUND PROPAGATION

The above categories show the ray paths along one azimuth and it is necessary to look at a number of azimuths over 360 degrees to obtain a full picture of the sound propagation pattern. If the model is to forecast actual sound levels it is necessary to ascribe values to the returning sound rays and to include factors that account for the scattering of sound by turbulence and the excess attenuation caused by the ground effects described earlier. This is not easy theoretically and most acoustic forecast models require empirical prediction methods derived from experimental measurements.

The current forecast model used by the Meteorological Office, known as the Larkhill mark 2, was developed in conjunction with the University of Salford. It is a ray based model and is fully described in [3]&[4]. It was developed primarily for use at firing ranges for impulsive noise sources such as guns and explosives and its output provides estimates of peak sound pressure level. It could be used for other sources but would require more experimental work to determine the relevant input source levels and propagation constants.

A second model known as the LARRI (Larkhill and ray invariant) is currently under test. This is a hybrid model which uses a more rigorous ray tracing programme based on sound ray tubes with invariant properties which can be used to compute the sound pressure level at the ground. The rays of course do not penetrate the shadow zones and the empirical values derived for the Larkhill model are used here. Both models require a met data input of temperature and wind velocity at 150 m height intervals from the ground to 3000m. This information is obtained from radiosonde data and local ground stations. The LARRI model accepts more detailed data for levels near the ground since it has been shown that these influence the final predictions significantly.(fig 10)

Other models based on the Fast Field Programme (FFP)[5] and the Parabolic Equation (PE)[6] are currently under development and it is hoped that these will take into account the variation in frequency content that occurs as sound waves propagate through the atmosphere and allow computation of waveforms.

9. CONCLUSIONS

The physical parameters and processes described above can be used to explain the way in which sound propagates from high intensity noise sources. In particular explanations are available for preferential low frequency propagation and the anomalous observations made at large distances from the source. Calculating actual sound levels is more difficult but experience with current models suggests that most situations can be covered within an acceptable error band particularly taking into account the limitations of on-site meteorological data gathering.

The Larkhill Mk2 model has been used very effectively to reduce the number of complaints about excessive noise from firing ranges. But this has been by delaying firing or changing the source site, or in some instances by reducing the source by lowering the charge size. Similar tactics are not available at events such as pop concerts.

The modelling techniques can be used to explain the incidents of anomalous propagation and the application of climatological data to the model can also be used as an aid to planning, not only to site concerts away from sensitive housing, but to put them at times of the year when they are least likely to cause a problem. But what relevance has climatological data when predicting the one-off event in the UK?

10. REFERENCES

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11. ACKNOWLEDGEMENTS

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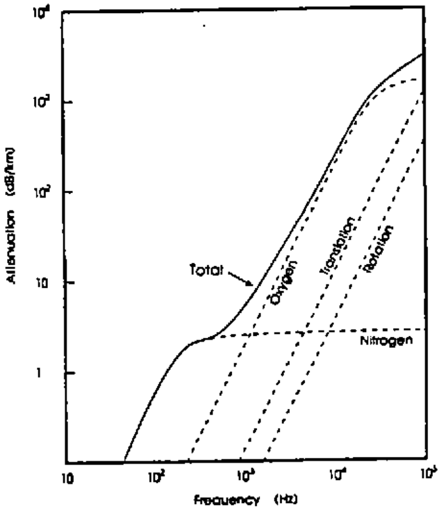
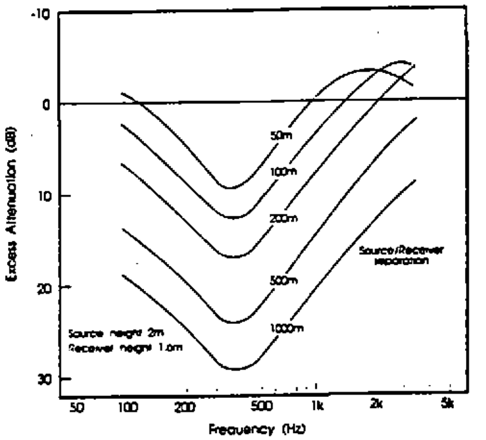
OUTDOOR SOUND PROPAGATION



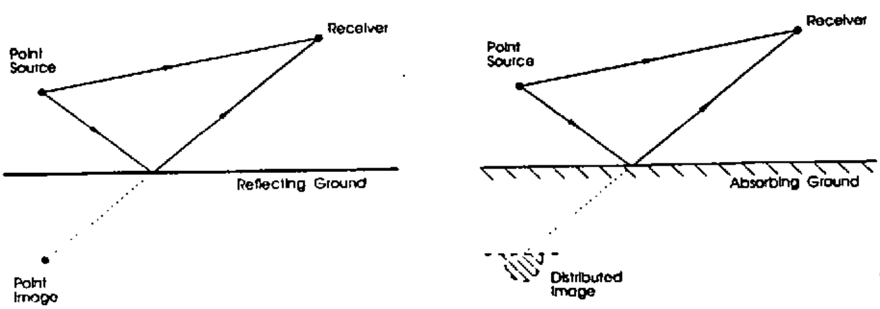
ATTENUATION OF SOUND IN AIR (50% RH, 20°C)

Figure 1 (Ref. 1)



TYPICAL EXCESS ATTENUATION DUE TO GROUND ABSORPTION

Figure 2



GROUND EFFECT FOR ELEVATED SOURCE AND RECEIVER

Figure 3

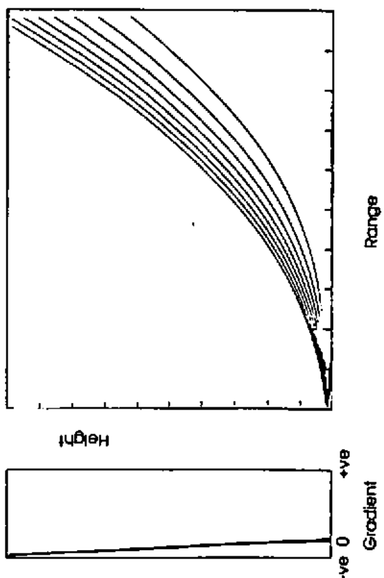


Figure 4

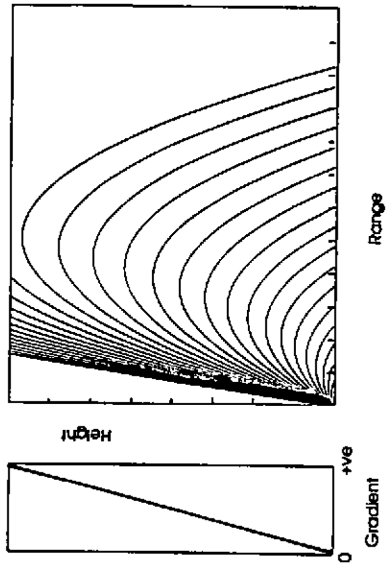


Figure 5

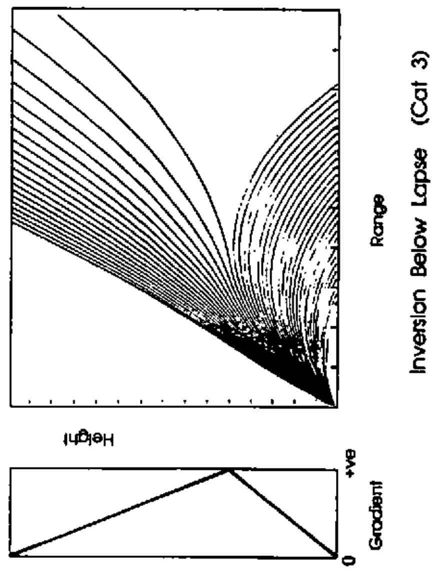


Figure 6

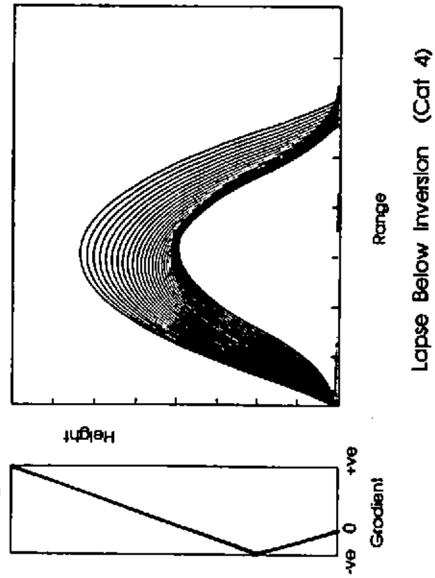
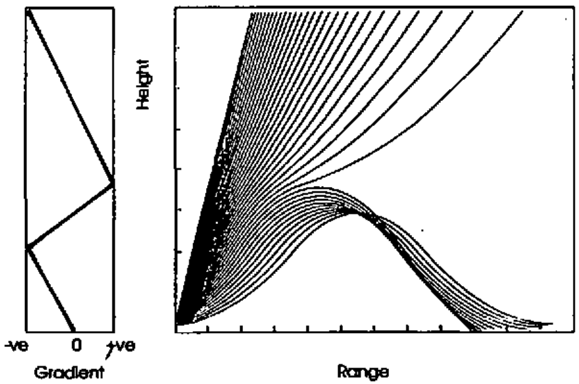
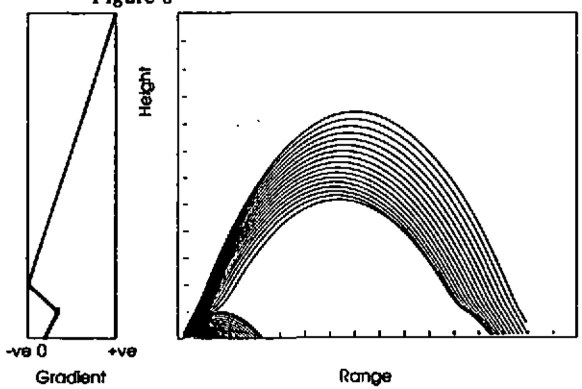


Figure 7



Lapse-Inversion-Lapse (Cat 6)

Figure 8



Inversion-Lapse-Inversion (Cat 7)

Figure 9

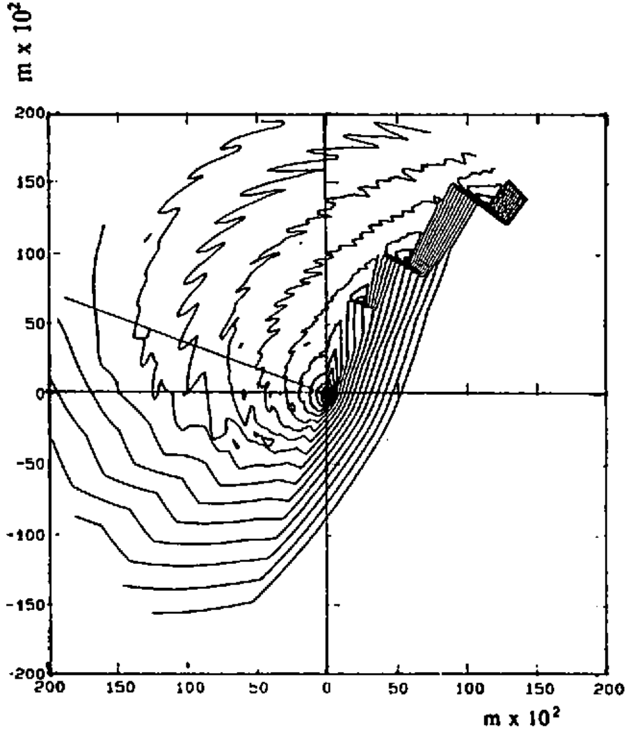


Figure 10 Example of LARRI plot