Hart District Council References 07/0064/MAJOR and 07/03197/MAJOR.

Hartland Park, Environmental Statement - Chapter D

Review of the Acoustic Statements

by
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Summary

This report is an unbiased review of the acoustic statements provided by the developer to support the planning application to build a distribution centre on the Hartland Park (Pyestock) site. It appears that substantial noise may be produced on this site by major loading and unloading activities at night-time. Consequently there is concern that the night-time noise radiated from these activities may exceed acceptable limits and cause sleep disturbance to local residents. The main issues revolve around the accuracy of estimated noise levels, the impact of night-time temperature inversions and the interpretation of the levels. The author has internationally acknowledged expertise on the influence of meteorology for noise mapping and is therefore equipped to assess the acoustic statements. Two standards, ISO9613 and BS4142, are quoted within the environmental statements and for clarification of their applicability and limitations the author has consulted committee members responsible for their generation. The issues may be summarised as follows:

- There is an unexplained reduction of 7dB in the estimated noise level given in the environmental statement of December 2007 compared with April 2007. The only acknowledged change is the application of ISO9613 to approximately account for the effects of meteorology on propagation. However the latter method would suggest an enhancement in noise rather than a reduction.
- A lack of understanding by the developer of the effects of meteorology on sound radiation is demonstrated in the erroneous validation exercise. Measurements are taken in unstable meteorological conditions of temperature lapse with no wind, which are unfavourable propagation conditions, and compared with ISO9613 estimates which are only relevant to favourable propagation conditions.
- The European Commission correctly quotes that temperature inversions are the most significant factor influencing sound propagation over moderate to large distances. Indeed significantly more noise enhancement than for downwind conditions is usually experienced. ISO 9613 is restricted to downwind conditions and an equivalent "moderate" temperature inversion. Contrary to claims by the developer this approach does not cover the range of typical temperature inversion effects. A more accurate prediction is required for this situation but in addition the frequency of occurrence of temperature inversions is needed.
- As there is doubt over the accuracy and relevance of the calculations a preferred measurement exercise is recommended of the noise radiated from an existing similar distribution centre to cover the relevant distances and the effects of changing meteorology over long time.
- Distribution centres are on the DEFRA list of industrial properties. Thus contrary to the developers claims BS4142 does apply and the background noise is within the scope of the method. The BS4142 guidance indicates that both of the estimated noise levels (first bullet above) are highly likely to lead to noise complaints.

1. Introduction

This review is in response to a request to provide an unbiased technical appraisal of the acoustic material within the Environmental Statement (Chapter D) for applications 07/00764/MAJOR [1] and 07/03197/MAJOR [2] for the proposed Hartland Park development at Pyestock. I am in a good position to review this material as I have technically managed several environmental noise assessments, including a strategic Higher Level Environmental Assessment [3] and others to do with Land Use Planning [4]. Also I have been instrumental in the development and validation of the most sophisticated acoustic propagation models [5] in the UK and on noise mapping tools [6] for the MOD where the accuracy of the predicted noise level is critical to survivability in military operations like hostage rescue.

For the proposed development of a distribution centre on the Hartland Park (Pyestock) site it appears that substantial noise may be produced by major loading and unloading activities at night-time. Consequently there is concern that the night-time noise radiated from these activities may exceed acceptable limits and cause sleep disturbance to local residents. An attempt is made [1,2] by the developer to estimate the likely noise levels but there are unexplained anomalies in the results and insufficient detail is provided on the acquisition of noise source levels and on assumptions used to derive the estimated levels. Specifically it is clear that the consultant has little practical or theoretical experience of the effects of meteorology and terrain on acoustic propagation, as can be observed by the absence of a comprehensive discussion of the effects and the erroneous attempt at a validation exercise (see section 6 below). A major concern is that in the revised environmental statement [2] emphasis is placed on the use of SoundPlan software, apparently acquired between April 2007 and December 2007, which cannot take account of the different meteorological conditions that are known to have a strong influence on the sound radiation. Indeed when NGTE used the Pyestock site the meteorology was constantly monitored on site to ensure that any night-time engine testing would only be undertaken in conditions which were unlikely to have noise impact on the local neighbourhood.

2. Background on Noise Prediction and Acoustic Refraction.

2.1 Predictability of Distant Noise Levels.

Outdoor noise and its variability during the day is an everyday experience of people with normal hearing. The variability may be due to changes in the source, e.g. increase in traffic flow during the rush hour, and due to changes in the meteorology. In order to make accurate predictions of the noise over large distances, exceeding 200m, it is necessary to have:

- an accurate model of the source noise, its frequency spectrum, its statistical variability and its directivity,
- a good representation of the ground conditions and of the topology, including detail of any barriers and vegetation, between the source and receiver, and
- an accurate measurement or prediction of the mesoscale meteorological conditions and its statistical variability.

The combined effects of the ground, topology and meteorology on acoustic propagation are diverse but with sufficient detail, as listed above, very accurate predictions of the mean noise level and its statistical variability are possible with modern tools [5,6]. With a well defined steady noise source the sound received by a distant observer varies substantially with time due to changes in the meteorology. The influencing factors are changes in time of the profile (gradient) with height of the temperature, wind speed/direction and turbulence. Typically a distant observer downwind in moderate wind conditions may experience a fluctuation in noise level by of the order of ± 10dB [4] in a matter of minutes due to atmospheric turbulence. Often only the mean noise level is quoted but, by its very definition, the mean level is exceeded 50% of the time and it therefore becomes more meaningful to ask how often, or what the probability is that, the noise exceeds a certain level. This is incorporated in the modern tools in use with the MOD.

2.2 Effect of Temperature Gradient.

Diurnal changes in the meteorology can lead to substantial differences in the noise experienced at night compared to the level during daylight hours. This is primarily due to different temperature gradients in the lower atmosphere. During daylight hours temperature lapse conditions usually occur which result in upward refraction of the sound away from the ground and in the absence of wind results in low noise levels in every direction at large range from the noise source. At night there are often cloudless low wind speed conditions in the UK which result in temperature inversions close to the ground. This results in downward refraction of the sound towards the ground, and produces high noise levels at large distances in every direction. The night-time temperature inversion conditions are noteworthy by the fact they are very stable conditions that vary very little over long periods of the night. Then the received sound does not vary substantially and can radiate to large distances with little attenuation. Also because inversions are established with low wind speeds the wind-induced background noise is also negligible. Generally it is also quieter at night in urban areas as there is less traffic and fewer commercial/industrial activities. So any additional noise radiated in these night-time conditions is significantly louder and subjectively more annoying compared with the background noise.

2.3 Effect of Wind Gradient

Any wind close to the ground will, because of the friction of the air with the earth’s surface, increase in speed with height above ground. The friction and hence the gradient is dependent on the restriction to flow (or roughness) caused by the ground, hills, vegetation and buildings. Thus the wind gradients, as well as temperature gradients, will be dependent on the local topology. This is the reason why, in the noise estimation procedure, ISO9613 [7] specifies the need for a local meteorological survey.

In the absence of any temperature gradient the wind gradient in the downwind direction will refract sound downwards towards the ground to produce noise enhancement. Upwind the sound is refracted upwards away from the ground. Old prediction tools would suggest no sound in the upwind direction. However there is not complete silence as sound is scattered by air turbulence into the upwind direction and is accurately predicted [4] by modern prediction tools.

There are opposing refraction effects in the combination of the upward refraction, in temperature lapse conditions, with downward refraction in the downwind direction. The combined effect can, depending on the wind gradient, be upward refraction “quiet conditions” or downward refraction “enhanced noise conditions”. In the upwind direction the combination with temperature lapse always produces “quiet conditions”. It should be noted that the wind changes direction with increasing height, because of the Coriolis forces, and consequently the downwind enhancement is not generally in the direction of the wind at ground level.

It is important to note that in temperature inversion conditions, which are only established with little wind, there is no opposition to the downward refraction of the sound. Consequently these conditions always produce enhanced noise levels in every direction from the source. The enhancements are more significant than for downwind propagation in temperature lapse conditions.

2.4 ISO9613 prediction capability

The ISO9163 method, adopted in the SoundPlan software used in the environmental assessment [2] is an estimation tool for approximate engineering solutions. It has ambitious aims at modelling the effects of the ground, trees, buildings and an estimate of the average effect of meteorology. As indicated in section 2.3 the topology influences the meteorology in a very complex way which cannot be predicted easily and certainly no simple engineering tool is available to do this. Thus the effects of the altered meteorology on the acoustics cannot be established by a simple engineering approach. Indeed the simplest idea would be neglect the meteorology altogether and assume the sound can be represented as straight sound rays interacting with the ground, trees and buildings.

The interaction with the ground can be accurately predicted using an ESDU model [8] where the ground is represented as a layered porous media with frequency dependent properties. This works well in conditions where refraction effects can be ignored; such as for highly elevated sources, i.e. aircraft, or for short distance propagation for sources close to the ground. In this situation the incident and reflected waves interact with each other to create reinforcements and cancellations as a function of distance from the source. These interactions depend on ground condition, frequency and heights of source and receiver. Walking away from a source the sound would appear to run through cycles of increases followed by decreases as distance is increased until eventually at grazing incidence the sound would steadily decrease with increasing distance. At this long range the broadband sound level for a non-absorbing surface, like concrete or water, would be about 3dB higher than the level obtained from the decay due to spherical spreading alone. On the other hand for a moderately absorbing surface, like grass covered sandy ground, the sound at large distance would be subject to additional attenuation over that of spherical spreading. The inclusion of the refraction effects of wind and temperature gradients dramatically alters this situation. In a downward refracting atmosphere sound rays are now bent in an arc to return to earth at large distance and then the main interactions with the ground occur close to the source and close to the receiver. The effects on the acoustics of the true meteorology are diverse and cannot be generalised. However in strong downward refracting conditions higher noise levels than predicted from spherical spreading alone are often experienced at long range for typical ground conditions.

One of the team responsible for the generation of ISO 9613 has stated that the method is based on the "state of knowledge" in the 1980's and hence is very out of date. Upwind and other unfavourable propagation conditions were ignored as there was no means of properly undertaking the calculation at that time. To derive an engineering solution several meteorological conditions were lumped together which were known to give very similar effects and the results were averaged. In this process there was a "moderate" night-time temperature inversion case (see chapter 1 of ISO9613 [7]) that could be identified as producing similar results to this average downwind situation. However as pointed out in section 2.3 this cannot be regarded as typical of average night-time inversion conditions which produce significantly more noise enhancement than in downwind conditions.

The method has its shortcomings and specifically it cannot produce results for a range of meteorological conditions. The WG-AEN report [9] makes a special reference to temperature inversions stating that "these are perhaps the most significant meteorological factor in the level of sound propagation over open ground over moderate to large distances". Indeed I would endorse this statement.

3. Difference in Predicted Noise Levels.

The developer needs to explain why the predicted $L_{Aeq,1hrc}$ noise level of 49dB, quoted in paragraph 6.18 of reference [1], has been reduced to 42dB in the more recent calculation (paragraph 6.25 of reference [2]). In the former case the predicted level is stated as missing the influence of the ground and trees. Therefore this prediction would appear to only include the effects of decreasing levels due to spherical spreading and atmospheric absorption. The more recent calculation [2] applies the SoundPlan prediction tool, which is based on ISO9613, to approximate for the influence in ground condition and the meteorological effects of downwind propagation.

On inspection of the algorithms employed in ISO9613 it is clear that for the distances involved in the current application the method always predicts enhancements over the combined effect of spherical spreading and atmospheric absorption, regardless of the ground condition. This is broadly in line with the physical interpretation in section 2.4 of downward refracting acoustic rays. The enhancement is illustrated by the 500Hz case, which is recommended in ISO9613 for use when only A-weighted noise levels are available, when ***increases of noise level of up to 8dB*** over spherical spreading are predicted for a source height of 2m and receiver height of 3.5m. It should be noted that the source height, the receiver height and ground condition influence the predicted noise level enhancement and therefore the assumed source height, for each of the identified noise sources, and the applied ground conditions need to be specified.

It is therefore unclear why the developer has reduced the noise level by 7dB in the application of ISO9613 when increases of up to 8dB are suggested by the calculation procedure.

4. Applicability of BS4142

4.1 Classification - Industrial Noise

It is surprising that only the fixed equipment (see [2] para 2.5.) is classified in the environmental statement [1,2] as "industrial" as intuitively one would expect the loading/unloading activities within the complex to be in the same classification. These latter activities are likely to swamp the fixed noise sources on the proposed site, particularly as the fixtures are amenable to noise control. Indeed distribution centres were listed under "industrial" in a recent survey [8] of LA's by DEFRA. Also a distribution centre is quoted as an example of industrial noise in a DEFRA report [10]. In addition a member of the on the committee which generated BS4142 [11] has also quoted that the standard applies to mobile sources within an industrial site and hence to a distribution centre.

4.2 Background Noise

In table 3 reference [2] the night-time noise levels $L_{A90,T}$ for 20th June 06 were measured to have an average of 30dBA, with levels reaching 32dB(A). Thus the measured background is within the scope of BS4142, which suggests that only levels below 30dB are too low for the standard to apply. However to illustrate the application of the method a case is examined in BS4142 [11] (example 4) with a background level of 31dBA. The latter is within the range of measured values given in table 3. I would therefore strongly disagree with the statement (para 6.35 of [2]) that the background is too low for BS4142 to be applied.

4.3 Rating level

This is not mentioned in the environmental statements [1, 2] but I would expect the proposed installation to produce noise containing distinct impulses (bangs and clatters). The source noise level would then need to be adjusted up by 5dB, to reflect subjective impact, as required by BS4142. From my experience such noise features may be produced by fork lift truck operations, although I note that some fork lift truck manufacturers are trying to address this problem.

4.4 Conclusion

There are two estimations provided for the noise level from the development. These are 49dB(A) [1] and 42dB(A) [2]. These are 19dB(A) and 12dB(A), respectively, above the average background level, and both are in excess of the 10dB threshold difference at which complaints about noise are likely. It is also highly likely that the noise produced will attract a 5dB correction for impulsive characteristics. The estimated noise level and source characteristics need to be clarified as BS4142 procedure indicates that the noise impact on the community could be unacceptable.

5. Applicability of ISO9613

5.1 European Noise Directive

As far as I am aware DEFRA has only endorsed the use of ISO9613, or software based on it, to adhere to the European Noise Directive (END) to map the noise throughout the whole of Europe. Strict Commission rules are applied with a common method (ISO9613) to ensure the results are not biased. The idea is to identify noise critical areas for a more serious assessment. Specifically ISO9613 is only regarded as the interim method [12] for the END. My colleagues at the Institute of Acoustics are not aware of any policy statement from DEFRA suggesting that ISO9613 should be used for local planning issues for industrial sites.

5.2 User Experience Required

It is apparent from my discussions with a member of the ISO9613 development team that the user needs to fully understand the limitations of the method in applications where the influence of real meteorology and ground condition may be important. As an experienced user my contact always indicates in any report that although the estimation is for conditions favourable to propagation higher levels may occur. He also recommends a careful calibration of the site before any calculation. This is in line with the recommendations from the EC working group WG-AEN report [9] on noise mapping that "every effort should be made to obtain actual, local data, which is representative of the area being modelled". In view of the erroneous validation exercise discussed in section 6 it would appear that the developer has not understood the propagation issues and limitations of ISO9613.

5.3 Choice of Parameters.

There are two parameters, G and C_0, that need to be selected when using ISO9613 that require user judgement and experience. It is not stated what values of G and C_0 have been used in chapter D [2] but this is very critical to the calculated sound level.

a) G is a ground parameter which can vary between 0 (hard surface) and 1(porous ground). Over the distances involved at Pontail this leads to received levels for hard ground being predicted to be 8dB greater than porous. How to select the appropriate ground parameter for a surface that is neither hard nor porous is not fully explained in ISO9613 so that it is entirely possible for two inexperienced users to obtain predictions that differ by 8dB. The advice I have received is that G=0.5 is appropriate for the terrain type between Pyestock and Pondtail.

b) C_0 is a parameter describing the long term effects (over months and years) of meteorological variations. ISO9613 suggests that it can take any value between 0 and 5dB. Note 20 of ISO9613[7] indicates that this can only be established by examining the local meteorological statistics but there is no indication of this being undertaken by the developer. However I have been advised that a long term correction should not be used in any calculation used for planning purposes.

6 Validation Exercise

A validation exercise involving the firing of a shot-gun is described in paragraphs 3.9 -3.13 and 6.28-6.31 of Chapter D [2]. Unfortunately the authors have overlooked some very important issues that negate their conclusions on the validity of the predictions based on BS9613, which they believe overestimate levels. The two issues revolve around the meteorology and properties of the gunblast as described below:

6.1 Gunblast

The blast from a gun is a transient wave with special characteristics. As a function of time the arrival of the blast at an observer location is accompanied by a sharp pressure rise to a maximum and then a pressure decay through ambient conditions into a suction phase before returning to normal (ambient) pressure. The duration of the blast wave is typically a millisecond or two, depending on the calibre of the3gun. This wave stretches as a function of distance from the source, as described in my paper ref [11] in 1981, through nonlinear effects. This is independent of any other feature like refraction, atmospheric absorption and any reflections. Non-linear interactions with the ground of the blast also have very different properties to that of a steady state noise source. Near to the gun, where the close-in measurement is undertaken, the measurement will record two separate transient waves, a direct and reflected wave as shown in ref [13]. These two waves coalesce as the wave radiates so the measurement at a distance will only consist of one blast wave. The consequence of the stretching and reflection is that the frequency content of the blast wave will change as a function of radiation distance. So any measured change in the spectrum, in the form of sound exposure spectral density, will not just represent the refraction component. It should be noted that the scope of ISO961 specifically excludes application to blast for this reason.

6.2 Meteorological conditions.

The meteorology described in paragraph 3.13 of ref [2], of a sunny day with no wind, are unstable conditions dominated by temperature lapse. The absence of wind means that all sound waves are radiated upwards away from the ground, producing a so called acoustic shadow around the source. In such conditions the sound would only reach an observer through scattering of acoustic waves by turbulence in the atmosphere. The nearest to this condition in my meteorological database has a wind speed of 2kts measured at the standard height of 10m, which would give very little air movement at human height. In this temperature lapse case the sophisticated propagation tools [5] predict about 12dB attenuation at 500Hz relative to spherical spreading at the distant microphone position. The ISO9613 calculation for 500Hz gives between 2dB attenuation to 5dB enhancement relative to spherical spreading, depending on whether soft or hard ground conditions are applied. Thus my prediction using real meteorology is between 10 and 17dB lower than the value estimated by ISO9613 method. So it is no surprise that in table 10 of ref [2] the measurement in lapse conditions with no wind is shown to be 9dB lower than the level predicted downwind by ISO9613. The “validation exercise” has only shown what would be obvious, i.e. lapse with no wind has less favourable propagation characteristics than downwind.

Thus the validity of the ISO9613 calculation is not proved.

7 Noise Source Description

The noise levels of 4 activities at existing service yards are provided in table 8 of ref [2] either as $L_{Aeq,T}$ or $L_{Amax.}$ However it is usual to represent the acoustic characteristics of the source in terms of sound power with a directivity factor as required for the input to ISO9613. How the measurements have been converted to the appropriate form for use in IS9613 needs to be explained. Also the standard applied in deriving the source levels needs to be quoted.

The representation of the fork lift loading noise by SEL suggests that it is a transient event but it is not clear whether this was because the fork lift was travelling past the microphone at close range or whether it was because of bangs and clatters. The nature of all sources needs to be described in order to establish if any rating is required. Also to apply the SEL source level in a prediction it is necessary to know the duration of the activity.

Knowledge of source height is required in ISO9613. As this height can have a large effect on propagation characteristics the developer needs to provide detail the source height that has been assumed for each activity.

7.1 Measured noise database

It is stated in paragraph 6.15 of ref [2] that the Sharps Redmore Partnership has undertaken an extensive series of surveys at existing yards to obtain appropriate source data for noise calculations. However measured data from the whole of a development is always preferred over prediction, unless the latter is validated and comprehensive. It is therefore recommended that noise from an existing distribution centre, with similarities to that being proposed, is monitored at appropriate distances over a period of several weeks. This way the true impact of the meteorology can be evaluated for the circumstances of concern at Pyestock. The noise levels could be scaled to reflect difference in the size and intensity of operation. This approach would provide the local authority with more concrete evidence of the likely impact of the distribution centre, whether the noise is acceptable and whether mitigation is required. The data could also be used to validate the ISO9613 prediction.

8 Effect of Woodland

In paragraph 6.27 of ref [2] it is intimated that the area between Pyestock and Pondtail consists of dense woodland which would produce significantly more attenuation than that calculated by ISO9613. Firstly the area is not densely wooded but even if it was the trees would have to be close to the source to have a significant effect.

A densely wooded area has a complex interaction on the microscale meteorology. The trees produce extra drag on the air the earth's boundary layer and consequently the wind gradients relative to the absence of trees are enhanced above the canopy. Almost still air exists under the canopy and the temperature gradients are modified. The net result is that the acoustic propagation over the trees is enhanced. So that if the source/receiver is sufficiently far from the trees the presence of the trees will enhance the propagation over woodland rather than introduce additional attenuation. This feature is recognised in annex A of ISO9613 with a calculation of additional attenuation only in those regions where sound ray paths intersect any dense foliage in the canopy. As much of woodland has been converted to heathland and there are now only a few isolated dense patches of trees the effect of trees on the propagation from the proposed site will be negligible.

9 Conclusions

- Concern is expressed over the unexplained reduction by 7dB (A) in estimated noise level from 49dB(A) in December 2006 to 42dB(A) in December 2007. It is understood that SoundPlan software, based on the ISO9613 procedure, was acquired and applied in the intervening period. However the method would appear to predict an increase in noise level by up to 8dB rather than produce a decrease. An explanation for the difference is needed.
- As there is doubt over the relevance and accuracy of the prediction noise level based on ISO9613 it is suggested that measurement around the whole of an existing similar distribution centre should be undertaken at distances of relevance to the proposed Pyestock development. If the measurements are undertaken over a long enough period, e.g. several weeks, the full range of meteorological effects on the radiated noise should be experienced. This data would also serve to validate the current predictions based on the measured source levels
- The official view is that BS4142 is applicable to all sources on the proposed site and the background noise level is within the scope of the assessment method. According to the guidance in BS4142 the levels predicted are likely to cause complaints.

- The nature of the noise source characteristics need to be explained. Some operations, like those using a fork lift, may consist of distinct impulses (bangs and clatters) that would attract a high weighting level to reflect extra disturbance features. This could increase the likelihood of a noise complaint.
- ISO9613 has only been endorsed by DEFRA for application in the European Noise Directive as an interim method to meet the short term requirements of producing a complete noise map of Europe. As far as the Institute of Acoustics is aware ISO9613, or codes based on it, has not been endorsed by DEFRA for use in planning applications.
- ISO9613 aims to estimate noise levels under favourable propagation conditions. The method is quoted as being able to represent "moderate" temperature inversion effects which may have similarity with downwind conditions. However it does not cover a typical range of night-time temperature inversion conditions where noise enhancements may be considerable higher than for downwind conditions.
- The validation measurement exercise is flawed by a) incorrect interpretation of the gun blast propagation characteristics and b) meteorological conditions that are unfavourable to propagation and hence cannot be compared against the ISO9613 calculations which assume favourable propagation conditions.
- The value of the parameters in ISO9613 needs to be explained together with assumptions on source heights and positions.
- The wooded areas between the proposed site and Pondtail are unlikely to provide any addition attenuation.

References.

1. Sharps Redmore "Hartland Park – Environmental Statement" Chapter D 07/00764/MAJOR April 2007
2. Sharps Redmore "Hartland Park – Environmental Statement" Chapter D 07/03197/MAJOR December 2007
3. Munt, R M, Browne R W, Simpson C and Williams T "Higher level environmental assessment of the noise levels of WAH64" QinetiQ report QINETIQ/FST/CR030289, January 2003.
4. Munt R M, Browne R W, Simpson C R and Williams T "Prediction of Helicopter Noise Contours for Land Use Planning" Paper AIAA-2004-281110th AIAA/CEAS Aeroacoustics Conference, Manchester, May, 2004
5. West M and Lam, Y L "Prediction of sound fields in the presence of terrain features which produce a range dependent meteorology using the Generalised Terrain Parabolic Equation (GT-PE) model", Internoise 2000, Nice, France, 2000
6. Munt, R M, Browne, R W, Pidd M & Williams T "A measurement and prediction method for determining helicopter noise contours" 27th European Rotorcraft Forum, Moscow, 11-14 September 2001
7. International Standard "Acoustics – Attenuation of sound during propagation outdoors – part 2 General method of calculation" ISO9613 – 2:1996 (E).
8. ESDU "The correction of measured noise spectra for the effects of ground reflection". Engineering Sciences Data Unit. Noise Series item 80038, November 1984.
9. European Commission Working Group "Assessment of exposure to noise" WG-AEN 002.2006, January 2006.
10. Bernard Berry "Review and analysis of published research into the adverse effects of industrial noise" DEFRA NANR5, March 2004.
11. British Standard "Rating industrial noise affecting mixed residential and industrial areas" BS4142: 1997

12. "Noise Mapping Industrial Sources" DEFRA Research Contract – Final Report Technical Report No: AT 5414/2 Rev 1, October 2003.
13. Munt R M, Perry A J & Moorse S A "Gunfire blast-pressure predictions" paper 16 of Agard Conference Proceedings No 318 - Dynamic Environmental Qualification Techniques -1981.