THE STATISTICAL ESTIMATION OF THE ATTENUATION OF IMPULSE PEAK LEVELS WITH RESPECT TO DISTANCE

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ABSTRACT: This paper presents a summary of experimental work carried out on impulsive noise propagation over distances up to 3.2 kilometers. The average attenuation of the maximum peak level (MAXP) is examined with respect to distance for all times of day and widely varying geographical and meteorological conditions. Formulae for predicting impulse attenuation are derived from the data using both spherical spreading and a curve of best-fit method. Possibly more important is the fact that the MAXP levels measured at any one location can lie over a wide range for example, up to 50 dB at 3.2 km. This has important implications for the prediction of annoyance and indicates that more consideration should be given to the statistical spread of results derived from experimental work.

1. INTRODUCTION

The propagation of peak impulse levels over distances in the order of a few kilometers can be very difficult to predict given the varying conditions of topography, terrain and weather. Many attempts have been made using basic ray trace methods[1], sophisticated computer models[2,3,4,5] and more recently statistical methods[8,9]. Of each of the techniques, the statistical methods seem to be more applicable in the field particularly with respect to impulse noise estimation. The prediction of peak levels is becoming a particular problem where urban areas are starting to encroach on locations that may have initially been considered remote in character, for example quarries on the outskirts of large country towns or cities.

There are many commercial noise prediction packages available that deal with predicted levels of noise from sources such as road traffic, industrial plant and other continuous noise operations. These will not be discussed here. The particular problem this project addresses is maximum peak impulse noise level (MAXP) during propagation. Specifically we address the impulse noise that originates from a source that commences as a shock wave from an explosion. The waveform of the impulse changes markedly during its propagation, with the most notable change being due to the rapid attenuation of the higher frequencies (this aspect of the study is not presented here as it is the subject of specific study and further analysis).

For this sort of environmental noise work what is often required in practice is not an 'accurate' prediction of noise levels but a range of possible noise levels that may be encountered over an extended period. This period will usually cover many and varied meteorological conditions and different times of day and night. These predictions may be required for operations from quarries located near urban areas, military test ranges and construction sites. The interest is in the annoyance these impulses have on the community and in many cases the specific noise level is of only secondary importance.

A brief report of a preliminary analysis of this data was presented in 1992[10,11] at a very basic level.

2. EXPERIMENTAL METHOD

The data was collected over an extended period from 1989 until 1991 from a series of seven field trips. The field trips consisted of eight days of measurements at each visit to each location.

Propagation is known to be greatly affected by meteorological and atmospheric conditions[1,5,14]. For this reason experimental measurement times were oriented over eight-hour periods that spanned sunrise and sunset as this covers the period when atmospheric conditions change most rapidly. For example if sunrise was at 6:30 am testing would commence around 4:00 am and conclude around mid-day. Afternoon measurements would commence around 2:00 pm and conclude around 10:00 pm.

An 'impulse' noise source was devised using a 125 gm mass of high explosive (Tovex, Powergel, Energex or similar). The explosive was located in an area of open ground and suspended on an open frame approximately two metres above the ground such that there was no impediment to propagation of the blast noise in any direction above ground level. The ground below the frame usually consisted of hard packed earth. Impulses were provided at the rate of about ten per hour.

Four manually operated recording stations were positioned at distances of 100 m, 800 m, 1,600 m and 3,200 m. The stations were positioned on a single radius from the source usually along a common access road. Each station had the capacity to store the Maximum Linear Peak Level (MAXP) of the impulse along with a record of the impulse waveform when it arrived at the site.

While local meteorological data could be obtained at each measurement location the overall meteorological conditions were monitored by the release of radiosonde balloons. The control and release of balloons and the recording of data from the radiosonde flights were co-ordinated by a meteorological unit from the School of Artillery of the Australian Army. The flight release point was located near but at a 'safe' distance from the impulse noise site.

The experimental sites were chosen from various locations around Australia and all, except for that at Bernacchi in the Central Highlands of Tasmania, were on military firing ranges. Sites were selected to represent different climactic zones ranging as far as practicable over as wide as possible Australian conditions from Northern Queensland to Central Tasmania. Military ranges were chosen as the Department of Defence was the main sponsor of the research and such areas have no difficulties with the use of explosives as impulse sources.

The Table 1 summarises the sites and the true direction of the measurement radius at each site. The site at Bernacchi was utilised twice, once in summer and once in winter.

Table 1. Summary of experimental site locations and propagation directions.

Summary of propagation directions (relative to geographical north)	
Innisfail, QLD	232°
Singleton, NSW	243°
Holsworthy, NSW	222°
Woomera, SA	184°
Port Wakefield, SA	0°
Bernacchi, TAS (x2)	143°

Thus while the propagation directions were not truly random they were only constrained by access and no other criteria.

The topography of the sites varied from rolling hills (Central Tasmania) to fairly flat (Port Wakefield and Woomera SA). Ground cover varied over all possibilities from dry, open grass with occasional trees to damp, muddy ground with snow patches and dense trees.

3. RESULTS

The results are presented in a 'concise' form and not in any way divided into regions, seasons or meteorological conditions (the subject of much more extensive studies carried out by NAL[6,7,10,12]). The data taken at altitude from the radiosonde flights are not reported here.

One of the objectives was to measure over the widest possible variation in meteorological conditions and hence give the widest range in impulse noise levels.

Meteorological data summary

Temperature – ground temperatures were in the range –5°C to +35°C.

Relative humidity – fell in the range of approximately 20% to 100%. Measurements were ceased when precipitation was such that equipment could be damaged. Otherwise measurements were carried out in reasonably damp conditions.

Wind direction and speed – Wind conditions varied over the complete spectrum in speed, from calm to very windy conditions, and direction, from 'up wind' to 'down wind' conditions. The only limitation was that measurements were unable to be carried out with wind speeds greater than 10 ms^{-1}. Various types of windshields were trialed for the receiving microphones used in the study until one particular type was found to be most satisfactory. This was a NAL (unpublished) design and in principle consisted of a square cross-section of side approximately 1.5m with an overall height of approximately 2.5m with an open top. A standard 200mm diameter, foam windscreen was also mounted directly on the microphone.)

The criteria for a satisfactory windshield was based on the impulse noise source reliably triggering the recording equipment (type 1 instrumentation with 'impulse' response time), while noise from the wind effects was ignored. The most critical position was the measuring location at 3,200 m as it usually had the lowest MAXP, although this was not always the case.

Acoustic data summary

In total there were about 2,500 impulse shots fired. However, not all of the shots provided data for all measurement locations at all times. The data was analysed statistically and a summary is provided in Table 2 below and illustrated in Figure 1. All data was normally distributed.

One point to note is that the minimum MAXP of 66.5 dB noted at the 3,200 m position does not necessarily imply that there were no MAXPs below this value. Under certain circumstances lower values of the MAXP at this position could be heard but were unable to be measured as they were effectively masked from the instrumentation by the background noise levels. Points that were uncertain and could not be positively identified were excluded from the study.

Table 2. Summary of average MAXP values against measurement distance.

Summary of the maximum peak level data					
Measurement Distance *d*	Average MAXP and standard deviation (σ) (dB)	Maximum MAXP (dB)	Maximum MAXP (dB)	No of valid data points N	95% Confidence Interval (dB)
100m	140.0 (1.8)	147.5	131.3	2103	(137.144)
800m	114.0 (5.1)	132.9	89.6	2148	(104,124)
1,600m	104.7 (7.4)	124.5	79.9	2147	(90,119)
3,200m	94.0 (8.9)	116.5	66.5	2035	(77,111)

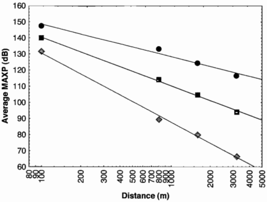

Figure 1 Average MAXP level (dB) with respect to distance (m) including upper and lower limits of MAXP: eqn 1 (square); eqn 2a (circle); eqn 2b (diamond)

The approximate relationship between MAXP and distance d, illustrated in Figure 1, can be written as:-

$$\text{MAXP (dB)} = 200 - 30 \log_{10} d\ (m) \qquad (1)$$

Figure 1 also shows the approximate upper and lower limits of MAXP as given by equations (2a) and (2b).

$$\text{Upper limit of MAXP (dB)} = 189 - 20 \log_{10} d\ (m) \qquad (2a)$$

$$\text{Lower limit of MAXP (dB)} = 217 - 43 \log_{10} d\ (m) \qquad (2b)$$

4. DISCUSSION

A comparison of the results with the free field attenuation rate of 6 dB per doubling of distance, suggested by the inverse square law in free space, and that proposed by Embelton2 of 6 dB per doubling of distance plus 3 dB per kilometer to take account atmospheric absorption, shows that neither are satisfactory with respect to the measured data. This comparison is summarised in Table 3 and illustrated in Figure 2.

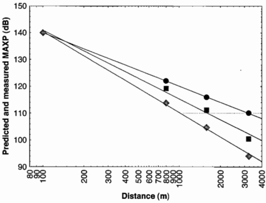

Figure 2 Predicted and measured values of MAXP (dB) with respect to distance (m) showing the 6 dB/doubling of distance (circle); 6 dB/doubling of distance + 3 dB/kilometer (square); and average measured values of MAXP (diamond)

All of the predicted values are greater than the average measured values, showing that the average attenuation is greater than that expected from simple spherical spreading including an absorption factor of 3 dB/kilometer.

The average attenuation of the MAXP with respect to distance is summarised in the last row of Table 4 and in Figure 3.

It can be calculated that for the data obtained the attenuation of MAXP, relative to the MAXP value at 100 m, with respect to distance can be reasonably approximated by the equation:-

$$\text{Attenuation of MAXP (dB)} = 27.6 \log_{10} (d/100) + 0.0014(d - 100), \qquad (3)$$

where d is expressed in metres (see Figure 3, full curve). This represents an average attenuation of 8.3 dB/doubling of distance with an absorption rate of 1.4 dB/kilometer.

The closest approximation that can be drawn in terms of spherical spreading is a curve with 6 dB/doubling of distance and an absorption rate of 5.8 dB/kilometer. This curve is also

Table 3 Comparison of measured average MAXP and suggested predicted values at measurement distances

Attenuation conditions	Average MAXP (dB) measurement at distance			
	100 m	800 m	1,600 m	3,200 m
6 dB/ doubling of distance	140.0*	122.0	116.0	110.0
6 dB/doubling + 3 dB/kilometer	140.0*	119.6	111.2	100.4
Measured values	140.0	114.0	104.7	94.0

Note: * *value taken as reference*

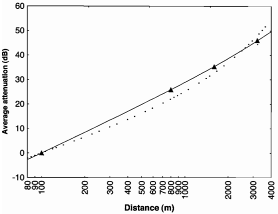

Figure 3 Line of best fit for the attenuation of MAXP (dB) and spherical spreading approximation for attenuation of MAXP including an absorption factor of 3 dB per kilometer with respect to distance (m): eqn 1 (full line), eqn 2 (dashed line)

illustrated in Figure 3 (dashed curve), and can be expressed as:-

Attenuation of MAXP (dB) =

$$20 \log_{10}(d/100) + 0.0058\,(d - 100) \qquad (4)$$

This absorption rate is almost double that previously suggested 2 of 3 dB/kilometer. It can be seen that the fitted, spherical spreading curve does not fit the data as well as the experimental curve derived above. However, considering the spread of the MAXP levels (discussed below) this curve could represent a reasonable first approximation.

A comparison of attenuation derived from spherical spreading with 3 dB/kilometer, 5.8 dB/kilometer, the experimentally derived "line of best fit" curve and the average measured values is presented in Table 4.

Perhaps the most important feature of the data summary is the spread in values of the MAXP. When the standard deviation at each distance is compared to the range of MAXPs respectively it can be seen that, while the standard deviation is of a reasonable size, the range of possible MAXP values is quite large due to the large sample size. These are summarised in Table 5.

Table 5 The range of MAXP values at each measurement distance compared to the range of the 95% confidence interval at each distance

Range of MAXP with respect to measurement distance and standard deviation		
Distance (m)	Range of MAXP (dB)	95% confidence interval (dB)
100	16.2 (+7.5 to –8.7)	7.0
800	43.3 (+18.9 to –24.4)	20.0
1,600	44.6 (+19.8 to –24.2)	29.0
3,200	50.0 (+22.5 to –27.5)	34.8

The average value of MAXP at a distance of 3,200 m may be 94.0 dB (standard deviation 8.9 dB), but the actual value could have been anywhere in the range of 116.5 dB to 66.5 dB. For an individual exposed to these impulse noise levels, the 66.5 dB may not represent any particular difficulty, however, a MAXP of 116.5 dB may represent a considerable problem.

5. CONCLUSION

For the general case the average attenuation of impulse noise levels can be estimated using the equations presented. As discussed equation (4) has been shown to fit the average values provided by the experimental data out to a distance of 3,200m.

While most of the time the average MAXP levels may be acceptable, the wide range of levels experienced illustrates that conditions can and do arise so as to produce exceptionally low attenuation compared to predicted values. The attenuation may be so low as cause high MAXP levels and hence

Table 4 Comparison of measured and calculated attenuation values from three sources

Attenuation value source	Attenuation of MAXP (dB) with respect to distance (m)			
	100 m	800 m	1600 m	3200 m
6 dB/doubling + 3 dB/kilometer	0	20.1	28.6	39.4
6 dB/doubling + 5.8 dB/kilometer Eq. (4)	0	22.1	32.8	48.1
Experimentally derived curve Eq. (3)	0	25.9	35.3	45.9
Average measured values	0	26.0	35.3	46.0

annoyance in the community. Thus when attempting to gauge the community annoyance from noise originating from high level impulse sources, greater consideration needs to be given to the possible wide variation in maximum peak levels that can occur under some meteorological conditions.

Careful consideration of the meteorological conditions favourable to propagation in the direction of interest should always be undertaken even if this is only on some sort of empirical basis. Attempts have been made to develop sound propagation packages for impulse noise but to date they are not as reliable as would be desirable for predicting noise annoyance[4,15,16].

Meteorological conditions considered favourable to propagation are discontinuities such as large temperature gradients (inversions), wind shear and high wind gradients, particularly in the direction of interest. Favourable propagating conditions will tend to cause annoyance in the direction of propagation.

As propagating conditions can vary greatly from time to time, when attempting to estimate annoyance, predicted values of MAXP levels at a distance should be considered as a guide only, while more serious consideration should be placed on data related to the possible spread of results derived experimentally.

If meteorological conditions are likely to cause annoyance action may be initiated so that the particular event is postponed until more acceptable conditions arise. This may be a very simple administrative noise control measure, implemented at a local level, capable of maintaining good community relations.

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7. REFERENCES

1. Sach, GI *Long Range Blast Pressure Prediction*, Technical Note 59, Defence Standards Laboratories, Australian Defence Scientific Service, department of Supply Maribyrnong, Victoria (1961)
2. Embleton, TFW "Sound Propagation Outdoors – Improved Prediction Schemes for the 80s" *Noise Con Eng*, **18**, 30 – 39 (1982)
3. Smith, GE *Focusing on acoustic waves in a non-uniform atmosphere*, Materials Research Laboratory, DSTO, Maribyrnong (1989)
4. Ha, JA and Williams "Computer Modeling of Sound Propagation in the Atmosphere Above Irregular Terrain" The Institution of Engineers Australia, *Vibration and Noise Conference*, Melbourne, September 1990
5. Embleton, TFW (1996) "Tutorial on sound propagation outdoors" *J Acoust Soc Am.* **100**(1), 31 – 48 (1996)
6. Peploe, P *The Attenuation of Impulse Peak Sound Levels with Distance*, NAL Commissioned Report No 115, May 1995, National Acoustic Laboratories, Chatswood (1995)
7. Peploe, P *Effect of Meteorological Conditions on Outdoor Sound Propagation – A field Study,* NAL Commissioned Report No 128, September 1997, National Acoustic Laboratories, Chatswood (1997)
8. Schomer, PD and Luz, GA "A Revised Statistical Analysis of Blast Sound Propagation" *Noise Control Eng. J.* **42** (3), 95 – 100 (1994)
9. Schomer, PD "A Statistical description of blast sound propagation" *Noise Control Eng. J.* **49** (2), 79 – 87 (2001)
10. Williams, W *The attenuation of impulse peak levels with respect to distance – an interim report on a study in progress,* NAL report No 129, September 1992, National Acoustic Laboratories, Chatswood (1992a)
11. Williams, W "The Attenuation of Impulse Propagation Peak Levels with Distance" *Proc Annual Conference of the Australian Acoustical Society*, Ballarat, November 1992 (1992b)
12. Williams, W *The attenuation of impulse leak levels with respect to distance*, NAL report No 130, May 1993, National Acoustic Laboratories, Chatswood (1993)
13. ANSI S1.26 – *1978 Method for the calculation of Absorption of Sound by the Atmosphere*, Acoustical Society of America, New York (1978)
14. Berger, EH, Royster, LH, Royster, JD, Driscoll, DP and Layne, M *The Noise Manual*, fifth edition, American Industrial Hygiene Association, Fairfax, Va (2000)
15. Ha, J *3-Dimensional Ray Tracing for Acoustic Waves*, CSIRO Division of Mathematics and Statistics, Report No DMS-C92/26, Clayton, Victoria (1992)
16. Ha, J *AUSPAK II User's Guide*, CSIRO Division of Mathematics and Statistics, Report No DMS-C92/24, Clayton, Victoria (1992)