PREDICTION RESULTS AND VALIDATION OF LONG RANGE NOISE PROPAGATION FROM BLAST EVENTS

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Abstract

The UNAPS Long Range Noise Prediction model, developed by the US military, has been selected to obtain sufficiently accurate predictions of the resultant peak overpressure levels of loud blast events at large distances from the blast site – within approximately 5dB up to 100km from the blast site. The outputs from the model have been compared against the extensive noise monitoring of blasting carried out in 2001 and 2002. The model has been modified to specifically suit an Australian site and its requirements. Additional noise monitoring has also been carried out in 2004 to collect the base data in order to add a commonly tested blast source type into the model.

Introduction

A long range noise modeling tool is required to predict noise levels in the regions surrounding Australian facilities resulting from static charges and blast sources. From these forecast levels, the likelihood of a planned blasting test causing significant impact (such as high annoyance levels) for the specific blast type and meteorological conditions at the time of test can be determined. A decision to proceed (or not) with the planned blast test can then be made.

A previous comparison [1] of currently available long range blast noise prediction packages identified the Universal Noise Assessment and Prediction System (UNAPS) as being the most appropriate for Australian requirements.

Vipac was responsible for the preparation of data, testing and verification of the UNAPS software. This included a significant noise monitoring programme to measure long-range noise levels from blast tests, encompassing a survey carried out specifically to gain data in order to add a commonly tested blast source type into the UNAPS model.

Final provision of the software, including specialised training, is being carried out in 2004. Additional blast noise monitoring is proposed to further add to the programme’s range of selectable blast source types.

The model

Inputs and outputs

The UNAPS model uses vertical meteorological profiles, including temperature, humidity, pressure, wind speed and direction, at least up to 6000 – 8000 metres obtained by SODAR (or from radiosonde), in conjunction with topographical/terrain data and acoustic directionality and ray tracing algorithms. The model couples an inbuilt acoustic algorithm with the atmospheric algorithm which utilises upper air sounding and meteorological data. The acoustic directionality data (i.e. the directional form of the sound propagation away from the source) is based on Schomer's data.

The model requires terrain data at every 5° increment in angle (in plan view). The model includes terrain in 3D but uses only 1D atmospheric data. This means that it is not sensitive to significant horizontal changes in the meteorological conditions. The output from the programme plots the L_{peak} noise level every 200 metres at 5° intervals.

The required inputs are definition of a Geographic Area over which the blast is to be modeled, a blast location (latitude/longitude), the blast source type, the blast direction (angle in which the blast is fired), the blast weight (equivalent kilograms of TNT), blast height (metres AGL) and a meteorological data file.

The model generates a results file by carrying out a ray trace at 5º horizontal increments from north (0º). The graphical output then displays a line-drawing map of the geographic area and plots the resulting L_{peak} noise pressure contours over this map.

Modification for Australian requirements

The original US military’s UNAPS model was initiated with US geographical sites; the appropriate topographical data, including land terrain, water surfaces and place name labels for an Australian test site were sourced and converted to the required UNAPS format.

The sound propagation calculations were extended from the original 40km radius to 100km (from the blast site) to encompass the requirement of prediction of blast noise levels at greater distances. This modification has earned the programme the name of UNAPS-LR (long range).

Conversion from imperial (e.g. pounds of TNT) to metric (e.g. kilograms of TNT) was required, as was modification from US military nomenclature and spelling.

The blast angle at which the blast is fired was modified from degrees (º from north) to mils (6400 mils equivalent to 360º).

Cosmetic changes to the output files such as chart colours, text displayed on screen, field character length displayed and naming convention for output files, were requested to clarify the output and were modified by the US source code programmer.

The appropriate source data for an additional blast source type was determined from blast noise monitoring, and this type is to be added to the existing half-dozen types available from a drop-down menu in the programme. The method of determining the required source data is described in a following section.

Conversion from a latitude/longitude coordinate system to specialised grid coordinates, and automation of the generation of meteorological files from SODAR /Radiosonde output files were identified as desirable features, and may be addressed in future software upgrades, but were beyond the scope of the original UNAPS project.

Initial Blast Noise Measurement

Vipac was engaged to undertake noise monitoring in 2001 [2] in order to provide base data to assist in selecting the appropriate long range blast noise model.

Peak overpressure levels were measured simultaneously at a range of distances from 10m to 100km for various blast types (blast source and resulting detonation).

The noise levels at eight representative sites were measured for the initiating of the test source at 1.5m above local ground level. Ground vibration, structural vibration and peak overpressure levels were measured at nearby sites, but have been excluded from this document as these are not addressed by the UNAPS programme.

Monitoring Procedure

Dual channel spectrum analysers, sound level meters and digital DAT tape recorders were used to detect and record the noise levels. More than one detector was used at some sites for additional data and redundancy purposes. All equipment was checked and calibrated before and after the measurements, and microphones had approved windshields fitted.

Time trace recordings were triggered to record the time signature/profile of the blast wave. Measurements of the spectral content of the impulse and exceedances above a threshold were also determined. Instruments were chosen to have appropriate noise floors and thresholds.

Some data collection problems occurred including clipping/overload of some instruments (close to the blast site) and triggering was not activated on some devices; however, detector redundancy overcame most of these problems.

The noise data (unweighted/C-weighted, impulsive response) was processed and analysed to provide levels for a range of noise descriptors, including L_{peak}, L_{max} and SEL. The DAT recorders provided digital trace data (over the event period) and, after post analysis, spectral data (sound pressure level versus frequency).

The vertical trace of meteorological conditions with height (up to at least 15,000m) was recorded using two radiosonde balloons, one about an hour before and another around the time of the blast test. The parameters measured included temperature, humidity, dew point, wind speed, wind direction and air pressure.

The variation in ground level weather conditions was also obtained for a range of sites over distances of up to 100km. Hourly ground level data was acquired from five weather stations over the area and also at two of the noise monitoring sites.

Measurement Results

The ground level meteorological conditions in the area were typically: temperature around 18º to 20ºC, humidity between 60% to 80%, air pressure around 1018 mbar and a strong/gusty wind between about 6 and 8 m/s from the N to NNE.

The cloud conditions at around the time of the blast were scattered low-level strato-cumulus (approx. 1000m height) and mid-level alto-stratus and alto-cumulus (approx. 2000m to 4000m). Cloud type and level was determined from the synoptic chart and aerological diagrams and can be inferred from the temperature/dew point plots. In addition, there was a slight temperature inversion at around 4000m altitude.

Table 1 summarises the noise measurement results for each of the sites, providing unweighted peak sound levels (in dB) over the period of the event.

Site	Distance from Blast	Peak Sound Level L_{peak}, dB
1	100 m	> 145*
2	600 m	> 145*
3	1.2 km	140
4	2 km	133
5	4.3 km	128
6	11.4 km	126
7	45 km	115
8	90 km	98^

Table 1. Noise Measurement Results for the Monitoring Sites from the 2001 Blast.

* Exceeded instrument threshold (overload) – actual levels would have been higher.

^ No blast noise measured or discernible (ambient noise measurement given).

The measured peak sound pressure levels (unweighted) ranged from 140 dB at about 1.2km distance to less than 100 dB at 90 km distance. However, for intermediate distances (from 5km to 50km) the measured peak levels were 10 to 20 dB higher than expected. This implies that there were some amplification or focussing effects, perhaps resulting from the prevailing meteorological conditions (inversion/stable atmospheric layers and strong northerly wind) and effective propagation (minimum absorption) of the blast wave over water.

We note that these measured results are specific to that test's source blast source type and charge weights, and the meteorological conditions on that day.

Further Blast Noise Measurement

A second set of blast noise measurements was carried out in 2002 [3]. As per the original monitoring programme, peak overpressure levels were measured simultaneously at a range of distances from 10m to 100km for various blast types (blast source and resulting detonation), mostly at the original (2001) measurement locations. Noise levels only (no vibration) at these sites were measured during the test.

The monitoring procedure was as per the 2001 monitoring, including the collection of radiosonde meteorological data shortly before the testing began. Three sets of eight blast events were tested, with varying blast charge and detonation charge weights.

At some of the attended measurement locations, there were two distinct noise events audible for each blast test – the blast noise and the detonation noise – however at some locations the noise from the blast events was lower than the background noise level.

Measurement Results

The ground level meteorological conditions in the area were typically: temperature around 22º to 31ºC, humidity between 23% to 57%, air pressure around 1020 mbar and a 1 to 3 m/s ENE wind changing to a 3 to 5 m/s NNW wind by the end of the measurement period.

In addition, there was a very slight (~2º) temperature inversion between around 3000 to 4000m altitude.

Table 2 summarises the noise measurement results for each of the sites for one of the blast charge weights, providing unweighted peak sound level (in dB) over the period of the event.

Site	Distance from Blast	Peak Sound Level L_{peak}, dB
1	600 m	117 – 124
2	1.2 km	111 – 114
3	2 km	–
4	4.3 km	105 – 128
5	11.4 km	91 – 103
6	24.5 km	104 – 110
7	45 km	<99 – <111
8	90 km	93

Table 2. Noise Measurement Results for the Monitoring Sites from the 2002 Blast.

These noise level results presented are the blast noise levels L_{peak} (dB) from the blast event rather than the detonation, as these are of relevance to the UNAPS prediction programme.

We note again that the results presented here are specific to this test's source blast source type and charge weight, and the meteorological conditions on that day.

Additional blast source type

Programme requirements

The calculation of peak overpressure noise levels from a blast (static or directional) is based on an empirical formula utilising blast weight (originally equivalent pounds, now kilograms, of TNT). The characterisation of blast source type is based on a directionality parameter i.e. the distribution of sound relative to the blast direction.

In the programme source code, this directionality parameter is defined in 30º increments from the blast direction, with 0º being in the firing direction, and 180º being directly behind the blast source, as illustrated in Figure 1.

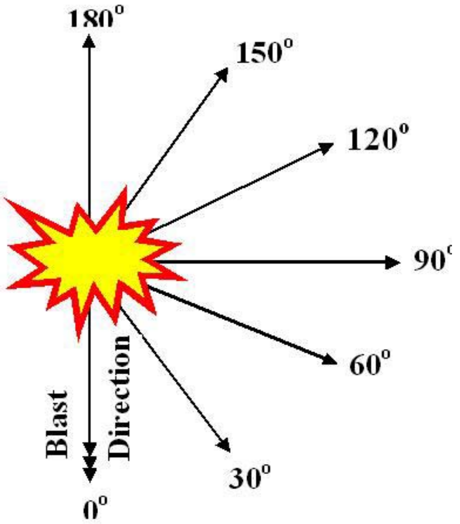

Figure 1. Directionality parameter locations

The directional factors are essentially a decibel correction, applicable in each direction from the blast direction, which is added to the overall calculated peak sound pressure level L_{peak} for that blast source type and charge weight.

Monitoring Procedure – Additional Source Type

Blast testing was scheduled early in 2004 [4] for a blast source type commonly used in Australia which was not listed in the original US UNAPS programme.

The monitoring sites were located at a distance of 3km from the blast site, and were distributed at 30° increments from directly behind the blast direction. It was initially desired to also include a seventh site, in the direction directly in front of the blast, however this was not permitted for safety reasons. The 180° and 150° direction sites were manned, with automatic noise logging equipment at the remaining sites.

Hand-held and remote noise monitoring Sound Level Meters (SLMs) were used to detect and record the overpressure (over a frequency range from 1Hz to 10kHz). Several different makes and models of equipment were used - Ono-Sokki, Brüel & Kjær and

Rion hand-held meters, and Larson Davis automatic loggers and hand-held meters. All equipment was checked, set up and calibrated before and after the measurements. Approved windshields were fitted at all times. Backup SLMs provided checks on measured levels.

Vertical trace recordings of meteorological parameters were acquired at the blast site on the morning of the tests using radiosonde balloon measurements. There was a balloon flight from the site approximately four hours before the first blast event. There was no cloud cover on the day of measurement.

Vertical trace data up to around 20,000 metres altitude was obtained for the parameters of temperature, humidity, dew point, wind speed, wind direction and air pressure. Figure 2 shows the vertical trace plot of temperature/dew point at the blast site on the day of the test.

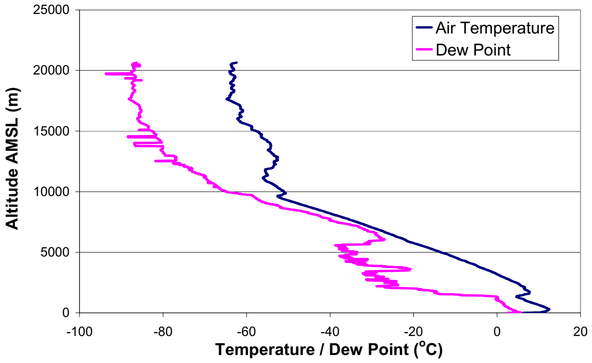

Figure 2. Temperature/dew point profile

This clearly shows a temperature inversion at around 1400m.

The test involved two sets of eight test blast events. Each of the eight tests involved different blast charge weights, and two detonation charge weights.

Measurement results

At each of the measurement locations, there were two distinct noise events audible for each blast event – the blast source noise and the resulting detonation noise. The time period between blast and detonation noise events was in the order of 5 seconds for the lower charge weights and in the order of 30 seconds for the higher charge weight. For the lower charge weights, the measured (and observed) sound pressure level from the blast was less than that of the detonation (i.e. the detonation was louder).

For the attended locations, individual measurements of blast and detonation noise events were able to be recorded by the operators. For the Larson Davis equipment, noise events were recorded by the equipment responding to a trigger (for noise levels greater than an predetermined threshold level), such that each noise event was recorded separately. The Brüel & Kjær and Rion equipment were set to measure the peak levels for a given time period, which was set as small as the equipment allowed – this was a one-minute interval for the Brüel & Kjær, and a ten-second interval for the Rion.

Therefore, for many of the blast/detonation events, particularly the smaller charge weights, both the blast and detonation noise events occurred within the same measurement period, such that only the highest of those levels was recorded.

After the blast events, the recorded data from each instrument (unweighted peak noise levels, L_{peak}, in dB) was calibrated, downloaded, processed and analysed. We note that for the first set of blasts, there was little wind on the ground, and meteorological conditions were effectively neutral. However, by the second set of measurements, there was a noticeable breeze from a southerly to south-south-west direction, which was verified by the Bureau of Meteorology's local data.

Therefore, the peak noise data taken from the first set of blast tests for the larger charge weights only was utilised in the calculations for the UNAPS software. Table 3 summarises the average blast noise measurement results for each of the sites (for the first set of measurements and the largest charge weight), which were utilised in the long range noise prediction software.

Angle	**Average Blast Noise Levels L_{peak} dB**
180°	109.5
150°	109.8
120°	113.1
90°	119.1
60°	123.1
30°	126.7

Table 3. Additional blast source type - Average blast noise levels

Generation of directionality constants

The overall calculated peak sound pressure level L_{peak} for the highest charge weight was determined from the UNAPS model for a unidirectional (uniform) blast.

Comparing this to the measured L_{peak} values in Table 3 gave the following directionality correction factors for the source type :

Angle (from blast direction)	**Correction factor L_{peak} dB**
0°	+6.6
30°	+2.9
60°	-0.7
90°	-4.7
120°	-10.7
150°	-14.0
180°	-14.3

Table 4. Peak blast noise correction factors (dB)

As we were unable to obtain data in the blast direction (0°), we were obliged to use the directional variables in the software for two similar blast source types already available in the UNAPS model to estimate the directional factor to be generated for the additional blast source in that direction.

Comparison of model to measured noise levels

In terms of accuracy, it is estimated [1] that UNAPS correctly delineates the sector, approximately 45-60 degrees of azimuth, where focusing occurs in about 80% of cases. The important aspect is not the exact sound level at a location but rather the general areas where focusing occurs and the relative magnitudes.

2001 Measurements

The UNAPS model prediction for the blast testing is shown in Figure 3.

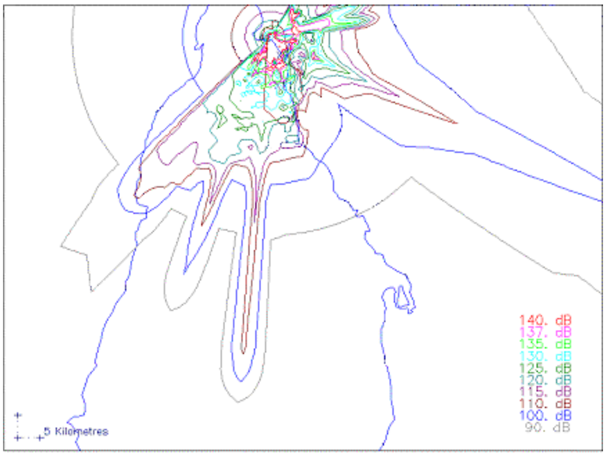

Figure 3. UNAPS noise contour plot, 2001

This clearly indicates the influence of wind direction on the day of test (NNE to 100m, NNW to 10,000m) and lack of acoustic absorption across the water to the south of the blast site.

The summary of measured compared with predicted peak blast noise levels for the testing in 2001 is shown in Table 5.

Peak Sound Level L_{peak} (dB)		
Distance	**Measured**	**UNAPS Predicted**
1.2 km	140	140
4.3 km	128	130 – 135
11.4 km	126	125 – 130
45 km	115	110 – 115
90 km	98^	<90

Table 5. 2001 – Measured vs. Predicted Blast Noise Levels (dB)

The results indicate that close to the source (within approximately 10km) the accuracy of the UNAPS model is limited, and tends to over-predict the peak noise level, while predicted noise levels at greater distances appear to be within 5dB of those measured.

2002 Measurements

The UNAPS model prediction for the blast testing is shown in Figure 4.

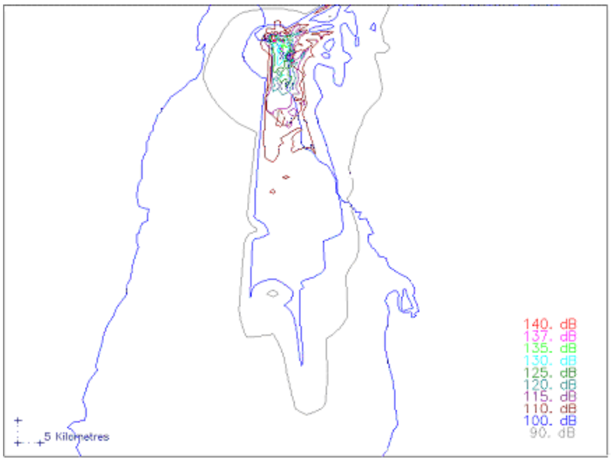

Figure 4. UNAPS noise contour plot, 2002

The summary of measured compared with predicted peak blast noise levels for the testing in 2002 is shown in Table 6.

Peak Sound Level L_{peak} (dB)		
Distance	**Measured**	**UNAPS Predicted**
1.2 km	111 – 114	115 – 120
4.3 km	105 – 128	120 – 125
11.4 km	91 – 103	115 – 120
24.5 km	104 – 110	100 – 110
45 km	<99 – <111	<90
90 km	93	<90

Table 6. 2002 – Measured vs. Predicted Blast Noise Levels (dB)

We note that at the time of writing, the actual blast source type tested in 2002 is not yet available in the UNAPS programme. Therefore for the comparison we have assumed a similar source type and blast height and direction, which have not been confirmed for the measured data, therefore the comparison between measured and predicted data may not be strictly accurate.

Nevertheless, the results indicate that close to the source (within approximately 10km) the accuracy of the UNAPS model is limited, and tends to over-predict the peak noise level, while predicted noise levels at greater distances appear to be within 5dB of measured.

2004 Measurements

The UNAPS model prediction for the additional blast source type is shown in Figure 5.

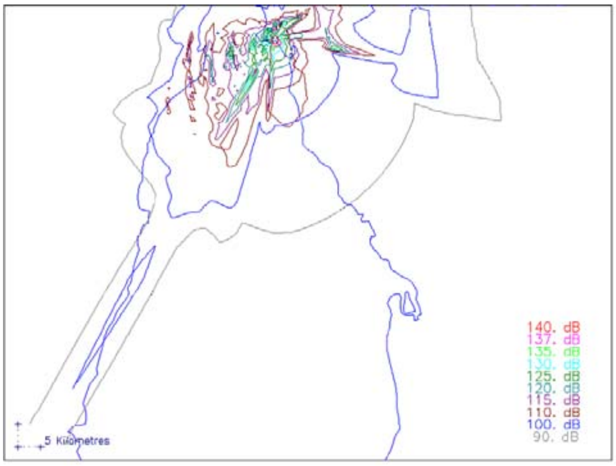

Figure 5. UNAPS noise contour plot, 2004

The summary of measured compared with predicted peak blast noise levels for the testing in 2004 is shown in Table 7.

Peak Sound Level L_{peak} (dB)		
Angle	**Measured**	**UNAPS Predicted**
0°	109.5	120 – 125
30°	109.8	110 – 115
60°	113.1	115 – 120
90°	119.1	115 – 120
120°	123.1	120 – 125
150°	126.7	130 – 135
180°	-	130 – 135

Table 7. 2004 – Measured vs. Predicted Blast Noise Levels (dB)

As for the 2002 predictions, we note that the actual blast source type is not yet available in the UNAPS programme, and the comparison is made against a similar source type; therefore the comparison between measured and predicted data may not be strictly accurate.

We note that, in terms of modelling the blast tests with the UNAPS software, the actual / measured blast noise distribution pattern varied from that predicted by the model using the radiosonde data, as the meteorological conditions had changed significantly in the four hours between the radiosonde balloon being released and the blast tests beginning.

We note also the unusual localised noise distribution within approximately 5 – 10km of the blast site, which indicates a "pocket" of high noise levels immediately to the north of the blast site, which accounts for the elevated predicted noise levels at the 0^o position.

Conclusions

Two far-field monitoring programmes for blast noise have been carried out in 2001 and 2002. The results have been compared against the predicted L_{peak} blast noise values and distribution given by the UNAPS programme based on the given meteorological and topographical profiles, as well as the selected blast source type, blast direction and charge weight.

Within the near field of the blast (approximately 10km), the accuracy of the UNAPS model is limited, and tends to over-predict the peak noise level; while predicted noise levels at greater distances appear to be within 5dB of measured, which provides sufficient accuracy for the application.

A near-field monitoring programme has been carried out in 2004 in order to gain data relating to blast noise distribution and directionality for an additional blast source type. Noise levels have been measured in a radial pattern at a distance of 3km from the blast site, and the data used to calculate directionality constants for inclusion of this source type into the next updated version of the UNAPS software.

References

[1] Broner Dr N., "Algorithm Review Report – Blast Noise Propagation", Vipac technical report 504618-TRP-012847-00, September 2001

[2] Teague Dr P., "Noise Monitoring Report *[full title withheld for reasons of client confidentiality]* – 5 June 2001", Vipac technical report 504618-TRP-012637-00, June 2001

[3] Blake S., "Noise Monitoring Report – *[full title withheld for reasons of client confidentiality]* – 7 May 2002", Vipac technical report 504618-TRP-013679-00, June 2002

[4] Foster R., "Noise Monitoring Report – *[full title withheld for reasons of client confidentiality]* April 2004", Vipac technical report 504618-TRP-016406-00, May 2004

[5] Teague Dr P. and Blake S., "Prediction of Long Range Propagation of Peak Overpressures from Blast Events", AAS National Conference 2002, presentation paper