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TNT BLAST SCALING FOR SMALL CHARGES

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Explosive equivalence to TNT is an established methodology to rank explosives and quantify their destructive effects. Concern has been expressed over the validity of the readily available empirical data, such as CONWEP [1], at small charge sizes, particularly given the significant oxygen deficiency of TNT.
A series of small TNT charges have been tested and their blast data compared to CONWEP. In the case of peak pressure the experimental results are in good agreement with CONWEP. The experimental observed impulse and blast wave duration were, however significantly lower. Hydrocode simulations were also in good agreement with the experimental results.
Analysis of the data indicates that this is due to the lack of full combustion of the explosive products, within the relevant time frame to contribute to the blast output.

INTRODUCTION

The use and importance of blast waves in target defeat mechanisms is well established. It is therefore important to be able to predict their magnitude. Existing semi-empirical models such as CONWEP [1] are extensively used to predict the magnitude of the peak pressure and impulse delivered to a target.

The experimental programmes to provide data for these models included the use of large amounts of conventional explosives, intended to generate blast waves with nuclear like signatures. Cullis [2] amongst others have expressed concern over the validity of the data within these models for small charge sizes.

Most semi-empirical models of free-field blast express the data with reference to the blast output of TNT. Different explosives are generally compared by means of their TNT equivalency both in terms of peak pressure and impulse. The TNT equivalency of an explosive is the ratio of the mass of TNT to the mass of the explosive such that both yield equal pressure or impulse. Most explosives are oxygen deficient to varying extents. As a result not all the available energy is released at detonation, some is released later due to combustion of the explosive products in air. This generally means that the pressure equivalency (detonation) and impulse equivalency (detonation and combustion) are different. TNT is 75% oxygen deficient by mass. The effect of this means that a TNT charge of 1.5 kg (charge radius 6 cm) requires the oxygen from the air out to a radius of 1m for full combustion.

A series of precise small-scale trials have been completed to investigate the blast output from small charges in comparison to CONWEP. TNT was the main composition within the experimental programme. To avoid the complications of ground reflections, hemispheres of TNT were tested and detonated from the centre.

To ensure that the data gathered was reliable, a large statistical sample of experiments was conducted.

In addition to the experimental programme a number of the scenarios were modelled using the cAst-Euler hydrocode. This would allow comparison of the experimental and simulations results. It would also allow examination of the effects of placing the TNT hemispheres on a platform, as direct placement would have damaged the trials pad.

EXPERIMENTAL METHODOLOGY

The purpose of the experimental programme was to provide precise blast measurements of small TNT charges. Particular care was, therefore, focused on calibration not only of the gauges but also ensuring the whole measuring system was accurate.

The experimental programme consisted of 11 hemispherical TNT charges nominally at 0.75 kg, 4 hemispherical TNT charges nominally at 6.0 kg, together with hemispherical PE4 (roughly equivalent to C4) charges and cylindrical TNT charges.

The blast measurements were obtained from 40 B12 blast gauges, and 2 PCB Electronics blast gauges. The B12 gauges were placed on two radials to allow blast measurements to be obtained every metre out to 40 m, a 2 m gap between gauges allowed the shock wave to recompose after passing the previous gauge and its support.

The 0.75 kg charges were placed upon a strawboard pack on an armoured plate set into the concrete trials pad, Figure 1. Some cratering was observed, hence one shot was placed directly on a metal plate to verify the assumption that this effect was unimportant. The large charges were placed upon sandbags on the armoured plate.

Complete system calibration was verified by dynamic calibration. This procedure involved injecting a known signal through each channel, and comparing to the signal recorded to determine magnitude losses/enhancements and signal profile. The rise time (frequency) of the signal, similar to the shock wave, had a rise time greater than the theoretically possible response time of a B12 pressure gauge. The observed variation in the results, –1.6% to +3.6%, was well within the standard limits of ±5%.

Before each shot the local climatic conditions were recorded to allow the data to be presented in the standard temperature and pressure reference frame of 288.15 K and 101325 Pa.

MODELLING

Three simulations were performed, two of the nominally 0.75 kg hemispherical TNT charges, and one of the nominally 6 kg charge. One of the 0.75 kg simulations included the exact trials scenario of the charge placed on the strawboard, with the pressure monitoring points at the gauge locations. The remaining simulations assumed the ideal situation, with the charge placed on the rigid boundary. The pressures were also recorded on the rigid boundary.

The simulations were modelled with the cAst-Euler hydrocode using a JWL TNT equation of state. As the JWL equation of state was derived from cylinder tests, no additional energy was added to account for after burning of the explosive products.

DATA PROCESSING

To ensure that the effects of charge size, and atmospherics were removed from the comparisons, the experimental data (peak pressure, impulse, time of arrival and positive phase duration) were corrected back to the standard reference frame. The data is plotted against scaled distance. This distance is not dimensionless. The scaled distances were obtained using the spherical equivalent mass. The scaling functions are explained in [3]. These functions corrected the pressure, impulse, arrival time and duration by up to 3%.

The PE4 scaled distances were also modified to account for its TNT equivalency. For PE4 the TNT pressure equivalency[1] is 1.37, the TNT impulse equivalency is 1.11.

Further scaling of the results was completed to present all the data on one graph for each attribute. Again the functions are explained in [3].

Ideally hemispherical surface burst and spherical airburst data would be equivalent, however real effects such as surface friction tend to decrease the pressures for the surface burst scenario. CONWEP data for both is presented. The predicted TNT equivalency for the experimental/modelling shots analysed is presented with reference to CONWEP surface burst TNT data.

RESULTS

Figure 1 shows the results (peak pressure, impulse, shock arrival time and pulse duration) for the nominal 0.75 kg hemispherical scenarios, including CONWEP, cAst, TNT and PE4 data, corrected to the standard reference frame. Figure 2 shows the results for the nominal 6.0 kg hemispherical scenario similarly corrected.

Both charge size results showed good agreement between CONWEP and cAst for the peak pressures and shock arrival time, with the experimental pressures slightly lower and arriving slightly later. Due to the gauge rise time the gauge records might have been expected to miss the peak. Good agreement was also observed between the experiment and cAst for the impulse and positive phase duration. CONWEP resulted in much longer durations and higher impulse.

The fully scaled results are displayed in Figure 3. These results showed similar good agreement between the over pressure and shock arrival time, and now good agreement between all results for the impulse (scaled by the duration). However the pulse duration still showed poor agreement. The different charge sizes were observed to correlate.

Close to the charge, at a scaled distance of 0.5 where the cAst result predicted a sharp fall in the pressure as the products enveloped the gauge the scaled impulse was predicted to be 4.5 times the CONWEP values. This result shows that CONWEP data should be used with caution close to the charge. The applicability of the blast scaling laws, has been suggested as $0.2 \leq P_{(peak)}/P_{(ambient)} \leq 20$ or $0.7\ m/kg^{1/3} \leq 6.6\ m/kg^{1/3}$ at STP [4].

Table 1, shows the mean TNT equivalency expressed with reference to CONWEP (hemispherical) data for peak pressure and impulse out to 40 m.

The results showed a few anomalies particularly on the duration where at 2 positions (one for each charge size) the duration was much too large. As these results were consistent it could indicate an effect of the geometrical experimental set-up, probably due to a ground reflection emanating from the edge of the backing plate. The simulation results more representative of the trials scenario tended to be closer to the experimental results than the ideal scenario, suggesting that the blast data was modified by the arena. It also reflected the CONWEP data that hemispheres (in reality) result in lower pressures than the spherical equivalent.

TNT Equivalency	Pressure (0.75kg)	Impulse (0.75kg)	Pressure (6kg)	Impulse (6kg)
TNT Hemisphere	0.76	0.67	1.06	0.72
TNT Cylinder	0.94	0.84	1.00	0.74
PE4 Hemisphere	1.03	0.84	1.25	0.85

Table 1. Pressure and impulse equivalency based on CONWEP data

DISCUSSION

The results were consistent both in terms of shot to shot repeatability and between charge sizes. The statistical sample and repeatability was sufficient to give confidence in the experimental result. cAst showed excellent agreement with the experimental data. However agreement between them and the CONWEP impulse data was poor.

The good agreement between the peak pressure and shock arrival time showed that the detonation properties from the cylinder test and CONWEP were accurate, and full detonation was achieved even for the small charges.

However the variation in the duration of the pressure pulse and impulse indicated that CONWEP over estimated the energy release from combustion of the explosive products in air. The good agreement between all the scaled impulse results confirmed this conclusion, particularly as the cAst results compared well to the experiment. The trials were conducted at 7–10 degrees C, high enough to ensure full combustion.

The variability of the blast output indicates that TNT is a poor explosive to rank other explosives, particularly as it is 75% oxygen deficient.

CONCLUSIONS

The repeatability and consistency from shot to shot and charge size to charge size shows that the care and attention to detail in arena preparation was justified and should be maintained. The statistical sample and consistency provides confidence in the data.

In these conditions full detonation of the charges was obtained, however CONWEP over estimated likely energy release due to afterburning, for both TNT and PE4.

The results, show these TNT charges have a mean equivalency for peak pressure of 0.8, and 1.0 for the 0.75 kg and 6 kg charges respectively, and a mean equivalency for impulse of approximately 0.7 for both sizes. This is significant in that the impulse from small charge sizes of TNT do not have a TNT equivalency of 1 (with reference to CONWEP data). The PE4 charges had similar equivalencies.

In the past criticism has been levelled at hydrocode modelling of air blast for under predicting the impulse, typically obtaining 75–80% of the CONWEP prediction for impulse. The good agreement between the results of these trials and the hydrocode simulations suggests that the hydrocodes have in fact been accurate in the modelling of air blast.

REFERENCES

1 "CONWEP" USAEWES/SS-R *US Army Engineering Waterways Experimental Station,* Vicksberg 1991.
2 I. G. Cullis, J. Gilbert, P. Greenwood, R. Pang, "Blast Wave Scaling and its Importance in Structural Loading", *Proceedings of the 16th International Symposium on Ballistics,* USA. 1996
3 G. F. Kinney, K. J. Graham, "Explosive Shocks in Air", Springer-Verlag, ISBN 3-540-15147-8.
4 S.G. Hookings, "The Limitations of General Blast Scaling Laws", *Modelling of Non-Ideal Explosives,* New Mexico, USA 1999

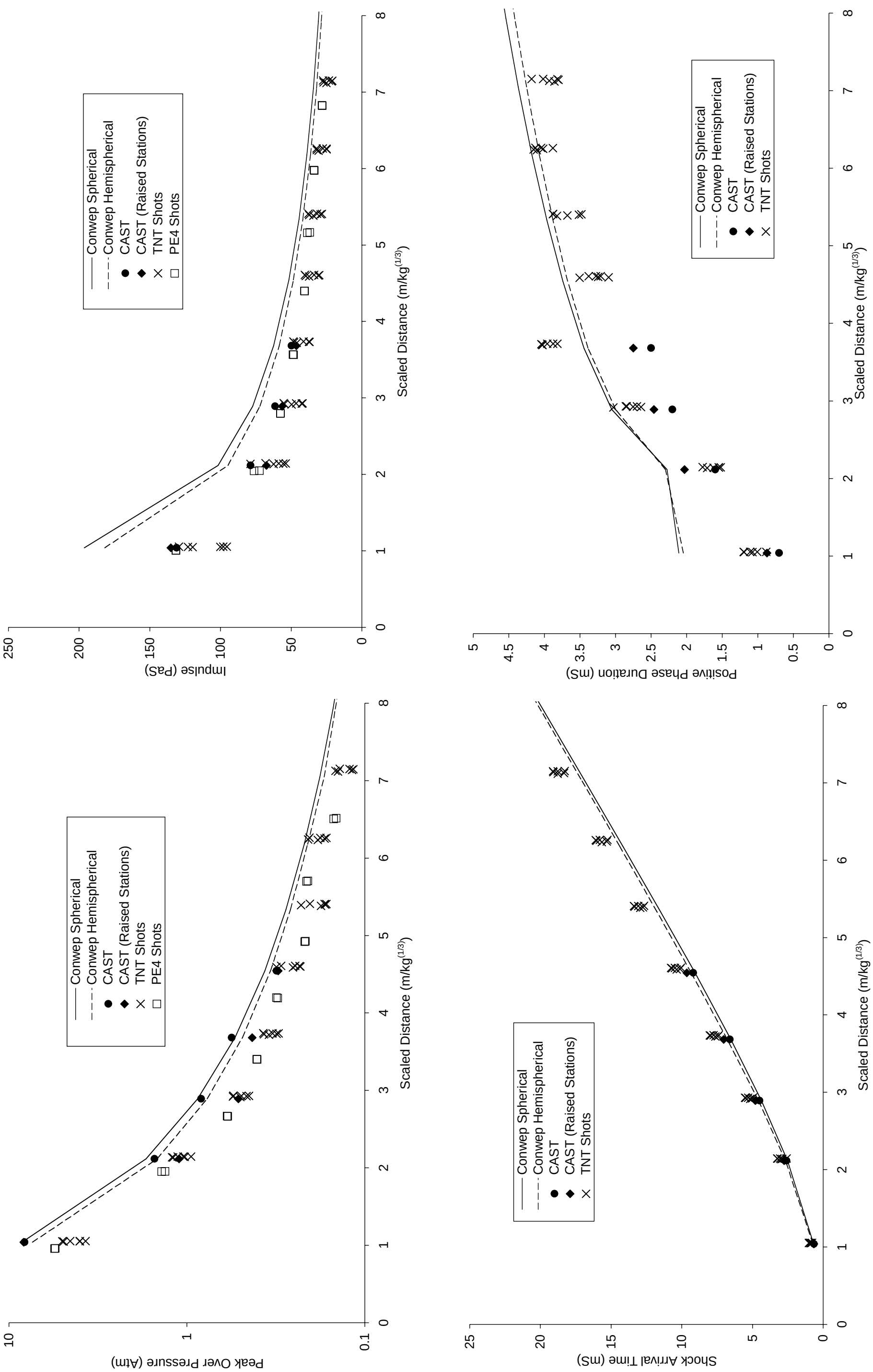

Figure 1 – 0.75 kg charge results.

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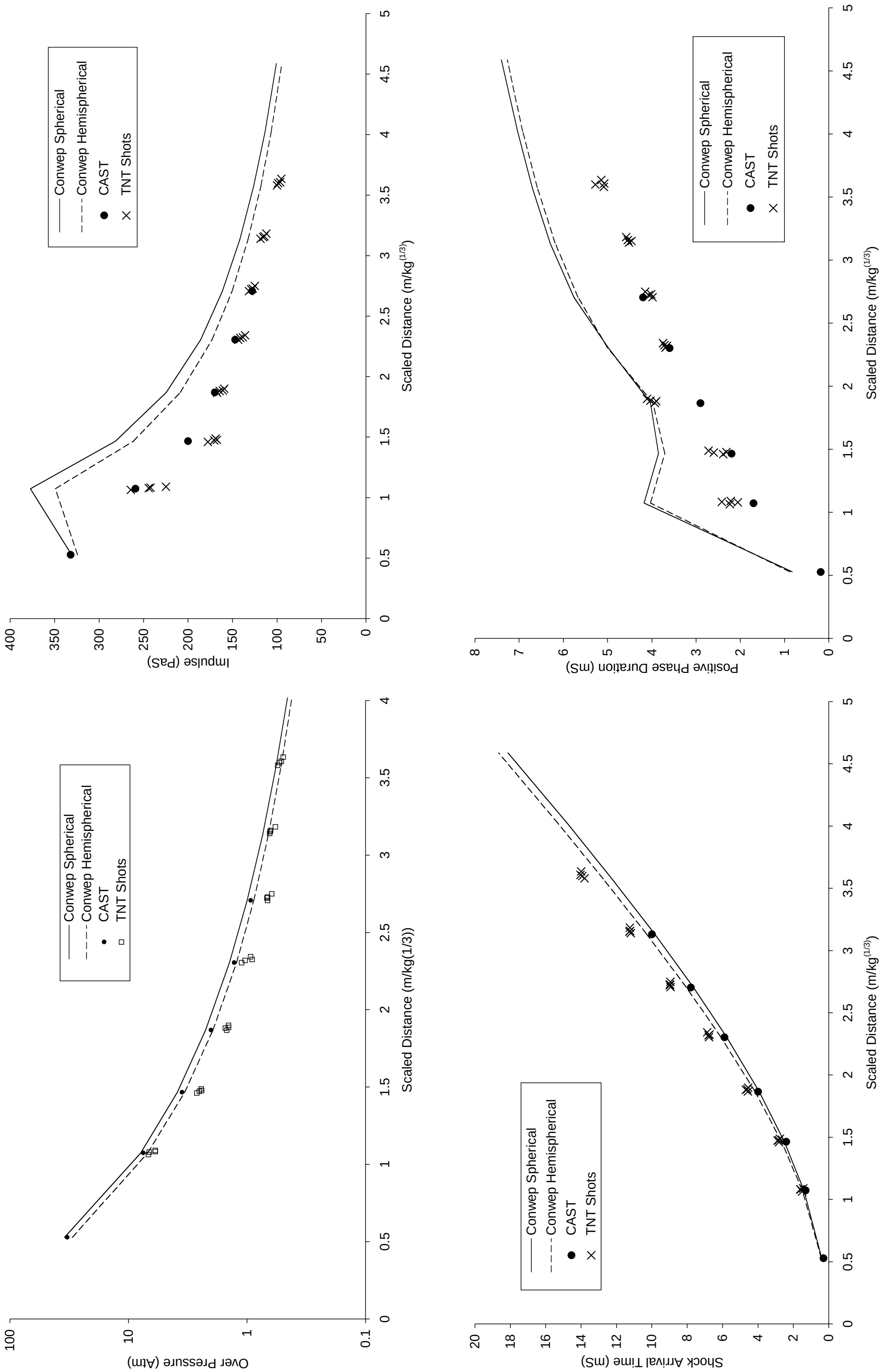

Figure 2 – 6.0 kg charge results.

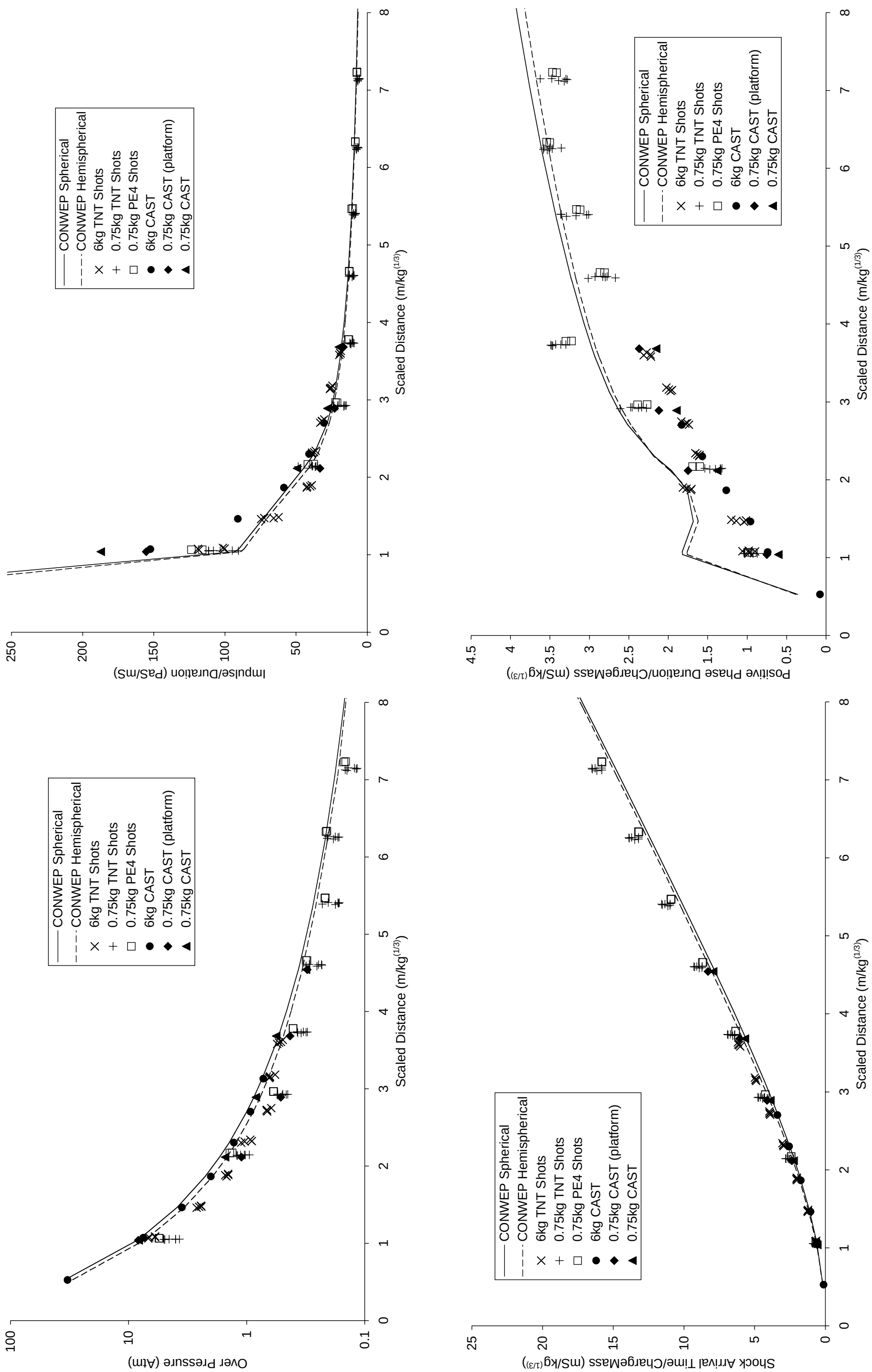

Figure 3 – Fully scaled results.