AIR-BLAST CHARACTERISTICS OF AN ALUMINIZED EXPLOSIVE

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AIR-BLAST CHARACTERISTICS OF AN ALUMINIZED EXPLOSIVE

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ABSTRACT

Air-blast characteristics of an aluminized explosive (RDX/ammonium perchlorate/aluminum/binder 20/43/25/12) were investigated . The TNT-equivalent weight factor of this explosive was experimentally determined as a function of peak pressure in the pressure range of from 0.7 to 120 psi. This factor was 0.9 for pressures over 10 psi (incident-wave region) and increased to 1.2 for pressures lower than 10 psi (Mach-wave region). It is believed that this increase in the TNT-equivalent weight factor in the low pressure region should be attributed to slow energy release from oxidation reaction of aluminum powder added in the explosive.

I. INTRODUCTION

When an explosive charge explodes in air, a shock wave is generated by the rapid release of chemical energy and it propagates through air. Properties of the blast wave represent some aspects of performance of an explosive charge, especially total energy release within relatively long time, compared to reaction time in military explosives. Therefore measuring blast parameters such as pressure and impulse makes it possible to deduce performance related with energy release; total energy release and approximate release rate.

The scaling law was developed to predict blast parameters for charges of an arbitrary weight. According to the scaling law, blast parameters are functions of only a scaled distance. The scaled distance is given by a distance from the explosion center divided by the cube root of charge weight [1]: $Z = R/W^{1/3}$, where Z is the scaled distance, R the distance, and W the charge weight. Since the total energy is determined directly by charge weight of a given explosive, it can be easily deduced that the scaling law is based on the assumption that blast parameters are related with the total energy release.

Different explosives release different amount of energy. The concept of TNT-equivalent weight factor (TNT EWF) was introduced to incorporate the difference in energy release between different explosives into the scaling law. The TNT EWF is defined as the ratio of the weight of a test explosive to the weight of a TNT charge which produces the same blast effect at the same distance. For most single-molecular explosives or mixtures of those explosives, energy release occurs within a very short time (in the order of 0.1 μs) compared to the time scale in which blast parameters are measured (in the order of 1 ms) so that the small difference in energy-release rate can be neglected. For this reason, the scaling law works well for most explosives. For these explosives, the TNT EWF is determined by using experimental data in a relatively high pressure range, typically over 5 psi. Although this factor is not constant, the deviation is not so big that the average value determined over the tested range of pressure is used in most applications.

It has been experimentally known that blast effect of an explosive can be enhanced by adding slow-burning energetic materials such as fine aluminum powder into the explosive. In this case, only a fraction of energy is released before the sonic point. As a result, the detonation velocity and pressure of this type of explosives are much lower than those of single-molecular explosives. Therefore it is natural to expect that the TNT EWF of this type of explosives be relatively low compared to those of single-molecular explosives for small scaled distance and that it increase gradually with increasing scaled distance. For this reason, using the TNT EWF determined in relatively high pressure region may result in errors in some applications.

The objective of this study is to experimentally evaluate the air-blast characteristics of an aluminized explosive in a wide range of pressure.

The plan of this paper is the following. Section 2 introduces the scaling law and the concept of the TNT-equivalent weight factor. Section 3 describes experimental techniques. Section 4 discusses the experimental results. Section 5 concludes this paper.

II. THE SCALING LAW

The scaling law for explosions is based on fundamentals of geometrical similarity: the ratio of volumes of two spheres is proportional to the third power of the ratio of diameters. Since the characteristics of a blast wave generated in an explosion depend mostly on the explosion energy release, two explosive charges of similar geometry and of the same explosive composition, but of different size, can be expected to give identical blast-wave intensities at distances which are proportional to the cube root of the respective energy release, or weight. This law is called Hopkinson's scaling law [2] after the formulator.

In this scaling law, the scaled parameters are [1]:

$$Z = R/W^{1/3} \quad \text{or} \quad R/E^{1/3} \quad \text{scaled distance} \tag{1}$$

$$\tau = t_a/W^{1/3} \quad \text{or} \quad t_a/E^{1/3} \quad \text{scaled time} \tag{2}$$

$$\eta = I/W^{1/3} \quad \text{or} \quad I/E^{1/3} \quad \text{scaled impulse} \tag{3}$$

where R is the distance from the explosion center, W the weight of an explosive charge, E the energy release of the explosion, t_a the arrival time of the blast wave generated by the explosion, and I the impulse. Then, blast-wave parameters, pressure, P, velocity, U, scaled time, τ and impulse, η, are given by unique functions of the scaled distance, Z, as follows:

$$P = P(Z) \tag{4}$$

$$\tau = \tau(Z) \tag{5}$$

$$U = U(Z) \tag{6}$$

$$\eta = \eta(Z) \tag{7}$$

Theoretically, once blast parameters are determined for a reference explosive, blast parameters of different explosives can be obtained from Equations (1) to

(7) if their weight or energy release is known. Usually, tables of blast parameters obtained from explosion of one ton of a reference explosive, usually TNT, are used as a reference (see reference [3]).

The scaling law and relationships expressed in the above equations may also be used in an inverse sense. They, then, permit the determination of the energy release for a given explosion from experimental data such as peak overpressure. The ratio of the energy release of a test explosive charge to that of a reference explosive charge of the same weight is called the equivalent weight factor (EWF). When blast parameters such as peak overpressure for the test explosive charge measured at the distance, R_t, are the same with those for a reference explosive charge at the distance, Z_r. Assuming that the experimental configurations for both charges are the same, the EWF of the test explosive is determined by using Hopkinson's scaling law, as follows:

$$R_r / W_r^{1/3} = R_t / (\mathcal{E} W_t)^{1/3} \tag{8}$$

so that

$$\mathcal{E} = (Z_t / Z_r)^3 \tag{9}$$

where

$$Z_t = R_t / W_t^{1/3}$$

and

$$Z_r = R_r / W_r^{1/3}$$

where $\mathcal{E}$ is the EWF of the test explosive with respect to the reference explosive, and subscripts r and t refer to as the reference explosive and the test explosive, respectively. When TNT is used as a reference explosive, $\mathcal{E}$ is called the TNT EWF.

III. EXPERIMENTAL TECHNIQUES

The test explosive used in this study is DXD-03, an experimental castable plastic-bonded explosive. The formulation of DXD-03 is RDX/AP/Al/binder 20/43/25/12 (weight %). The configuration of this explosive is shown in Figure 1. The density of DXD-03 is 1.78 g/cm^3 and the weight of a charge for this configuration is $\sim$ 13 kg. A booster of 90 g composition A-5 was used to initiate the DXD-03 charge. TNT and composition B charges of the same geometry except booster size were also tested for comparison.

The experimental setup for blast-effect tests is shown in Figure 2. As shown in Figure 2, a cylindrical charge was placed at a height of 1.9 m and was initiated from center. Pencil-type blast pressure gauges, PCB 137A11 and 137A12 manufactured by the PCB Piezoelectronics, Depew, NY, were placed at the same height with the charge and at distances from 3 to 60 m from the center of the charge. Signals from the gauges were amplified by the PCB 464A Dual-Mode Charge Amplifiers manufactured by the PCB Electronics, and recorded by the 6810 Waveform Recorder manufactured by the LeCroy Research Systems Corp., Spring Valley, NY, was used.

IV. RESULTS AND DISCUSSIONS

Experimental peak overpressures for DXD-03, composition B, and TNT in incident-wave and Mach-wave regions are shown in Figures 3 to 8. To calculate the TNT EWF for DXD-03, the data set in each region was fitted to a fourth-order polynomial by a least squared-error method, as is:

$$\ln P = \sum_{i=0}^{i=4} a_i (\ln Z)^i \tag{10}$$

where a_i are adjustable constants. Peak overpressure data for composition B and TNT were also fitted to Equation (10). By using fitted equations, scaled distances for DXD-03 and TNT yielding the same overpressure were calculated. The TNT EWF was calculated by using Equation (9). The results are shown in Figure 9. The TNT EWF for composition B was determined by repeating the above procedure, and the results are plotted in Figure 10.

When it impinges on a surface near grazing incidence, a shock wave produces a Mach wave (or Mach stem). A triple point is the point at which three waves, incident, reflected, and Mach waves, meet altogether. The farther the Mach wave propagates, the higher is the triple point. To check whether a gauge at a certain location is affected by the Mach wave or not, it is necessary to determine the locus of the triple point. The height of the triple point is usually given as a function of the height of the center of the explosion and the gauge height (see reference [4]). The calculated minimum distance at which a gauge was affected by a Mach wave was 6.5 to 7 m for DXD-03, TNT, and composition B charges tested in this study. Pressure records showed that the Mach wave started to affect gauges at 7 m from the explosion center. In the above triple-point calculations, all charges were assumed to be spherical. At the position of 7 m (scaled distance: 3 m/kg$^{1/3}$), the explosive yield of a cylindrical charge is greater than that of a spherical charge for the same weight, the calculated results might have been overestimated (but not shorter than 6 m).

It has been experimentally found that there exists significant differences in blast characteristics between cylindrical and spherical charges for the same weight. When a ratio of length to diameter is over 1, the explosive yield of a cylindrical charge is greater than that of a spherical charge at relatively small scaled distance and decreases with increasing scaled distance. For a cylindrical charge of 2 kg composition B, its explosive yield was equivalent to that of a 3 kg spherical charge at an overpressure of 60 psi and that of a 1.7 kg spherical charge at an overpressure of 5 psi [5]. In this study, the EWF of the cylindrical TNT charge with a length-to-diameter ratio of 1 is shown in Figure 11. In the above calculations, explosion properties of a spherical TNT charge was obtained from standard tables for explosion of 1 ton charges listed in reference [3]. To eliminate the above geometry effect in evaluating the blast effect of DXD-03, explosive yield of cylindrical TNT charges were used as a reference in this study.

As shown in Figure 9, the TNT EWF for DXD-03 was determined to be 0.9 in relatively high pressure region (incident-wave region) and 1.2 in relatively low pressure region (Mach-wave region). This trend was much different from that of TNT EWF for composition B, which was almost constant in both regions. These results suggested that the energy release of DXD-03 charges was lower than that of TNT charges in early stage of detonation and was greatly increased in later stage.

Experimental detonation velocity and pressure data supported this reasoning. The detonation velocity of DXD-03 was determined to be 5.49 to 5.70 km/s at charge diameters of 45 to 127 mm [6,7]. The BKW code predicted the detonation velocity of DXD-03 to be 7.81 km/s. The detonation pressure measured by the high-resistance manganine-gauge method was 14 GPa [8] while that predicted by the BKW code was 27 GPa. The big difference between the experimental data and the BKW predictions suggested that a significant part of energy be released after the sonic point and that DXD-03 be a nonideal explosive.

Since only a fraction of energy was released before the sonic point, the energy yield of this explosive was measured to be low in vicinity of the charge or in relatively high pressure region. As the rest of the energy was released, the TNT EWF was increased. This energy release behavior is quite different from that of most single-molecular explosives, energy release of which occurs within very short time (in the order of one tenth of μs). Because of this fast energy release, TNT EWF for single-molecular explosives obtained in relatively narrow pressure range may be used in most applications without causing big error. The TNT EWF for nonideal explosives such as DXD-03 obtained in relatively high pressure region, however, cannot be applied to relatively low pressure region.

The pressure criterion in determining inhabitated building distance (IBD) regulated in the DOD standards [9] is 0.9 psi. Using the TNT EWF value for nonideal explosives determined in relatively high pressure region in determining IBD may result in underestimation of IBD. In this case only the TNT EWF value obtained in pressure region near the pressure criterion should be used for correct results.

In conclusion, the addition of aluminum powder caused slow energy release and, consequently, improved energy yield at relatively low pressure region.

V. CONCLUSIONS

The air-blast characteristics of DXD-03, an aluminized explosive, were investigated. The TNT EWF for DXD-03 was determined to be 0.9 in relatively high pressure region and 1.2 in relatively low pressure region. It is believed that the increase in the TNT EWF in relatively low pressure region should be attributed to slow reaction of aluminum powder.

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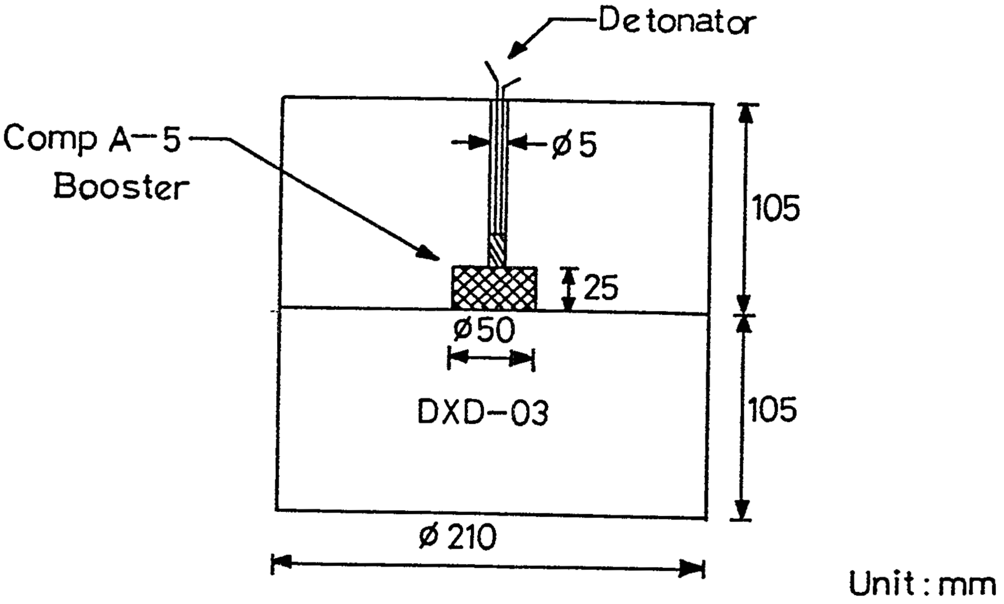

Figure 1. Configuration of a DXD-03 charge (~ 13 kg).

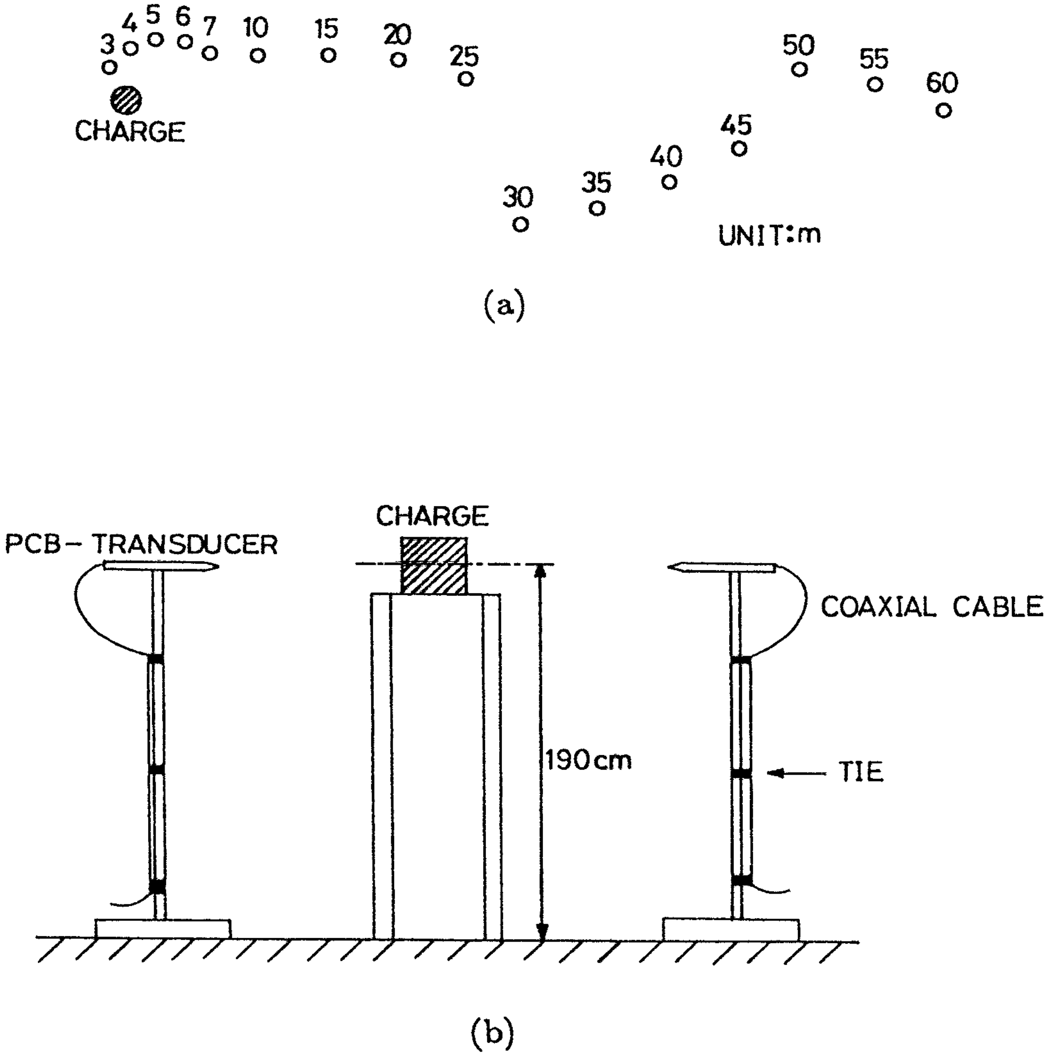

Figure 2. Experimental setup of blast-effect test; (a) gauge location and (b) height of a DXD-03 charge and gauges.

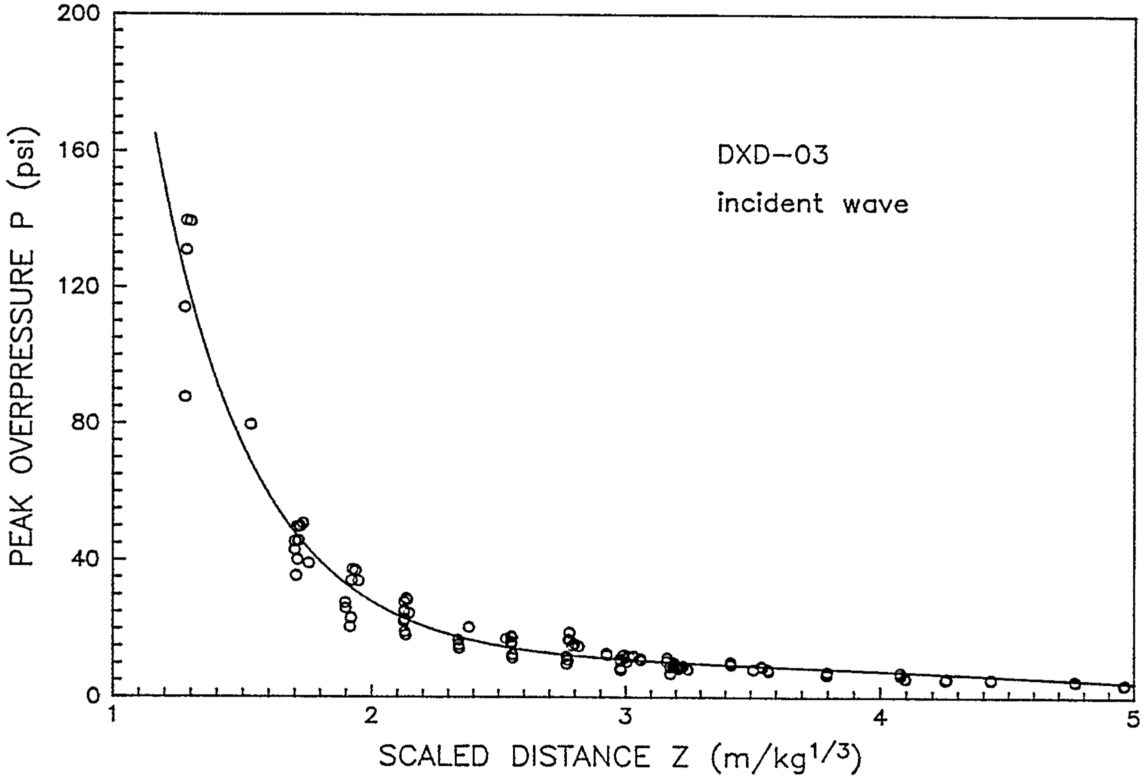

Figure 3. Overpressure as a function of scaled distance in incident-wave region for DXD-03 (~ 13 kg).

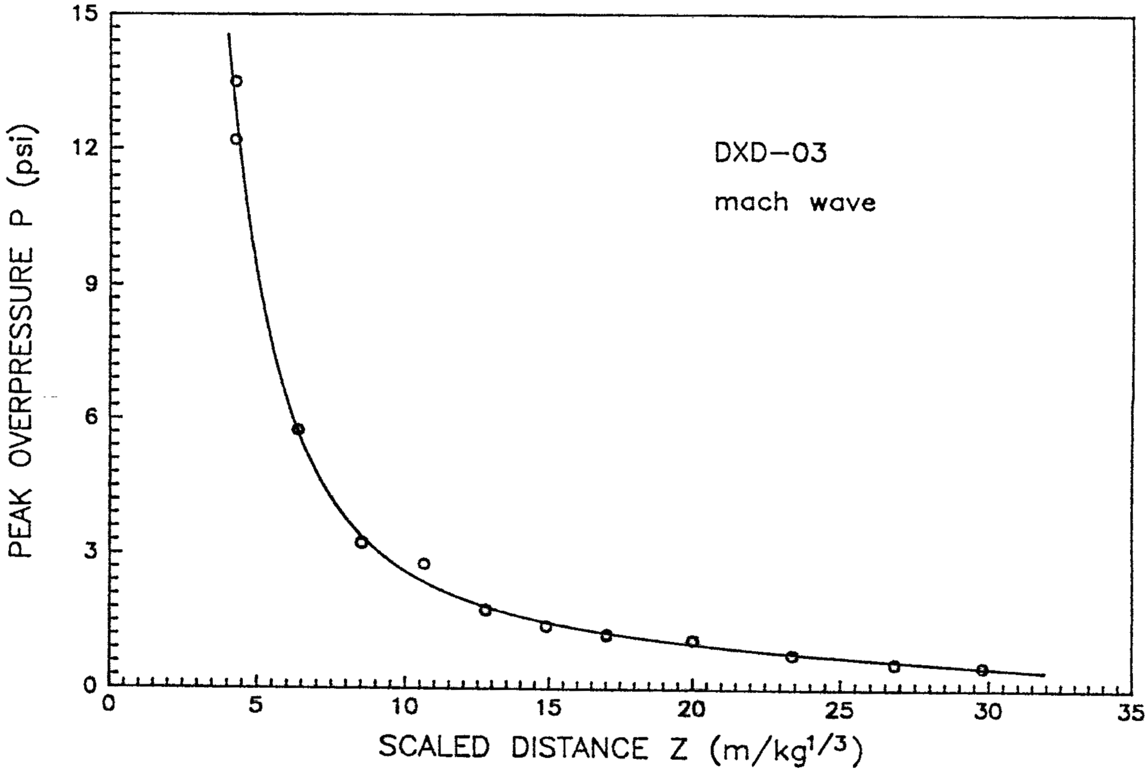

Figure 4. Overpressure as a function of scaled distance in Mach-wave region for DXD-03 (~ 13 kg).

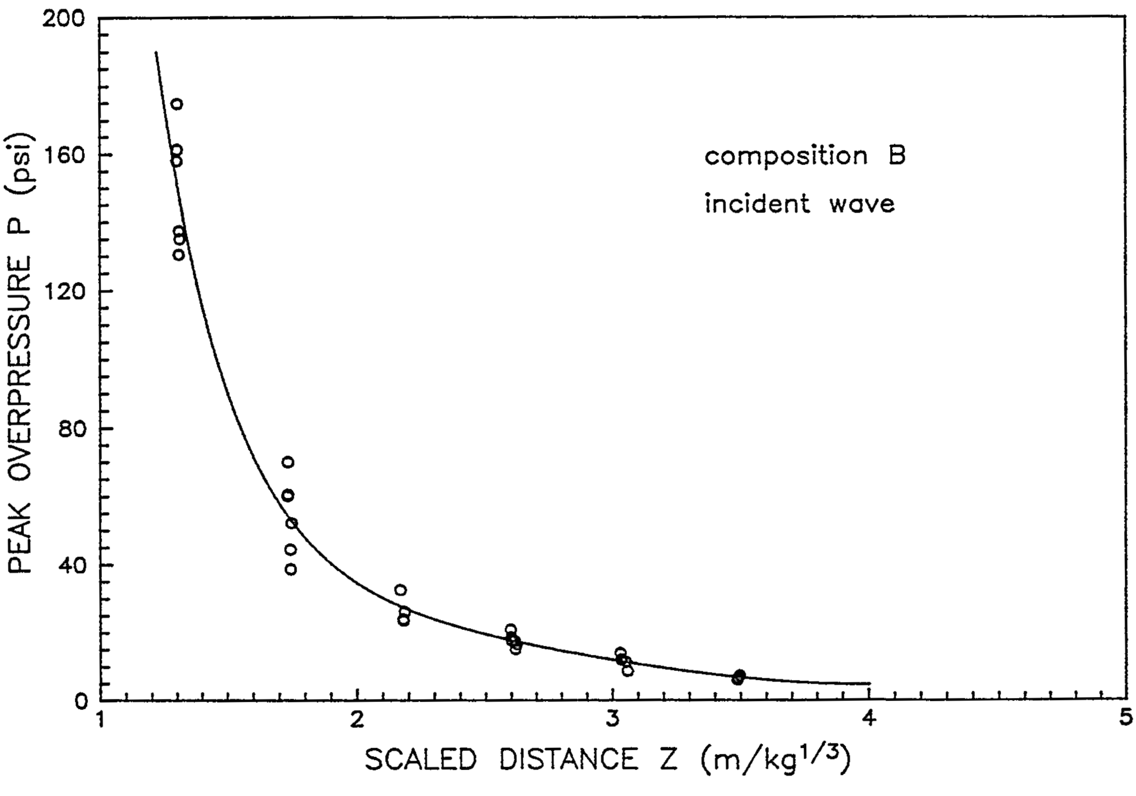

Figure 5. Overpressure as a function of scaled distance in incident-wave region fo composition B (~ 12.3 kg).

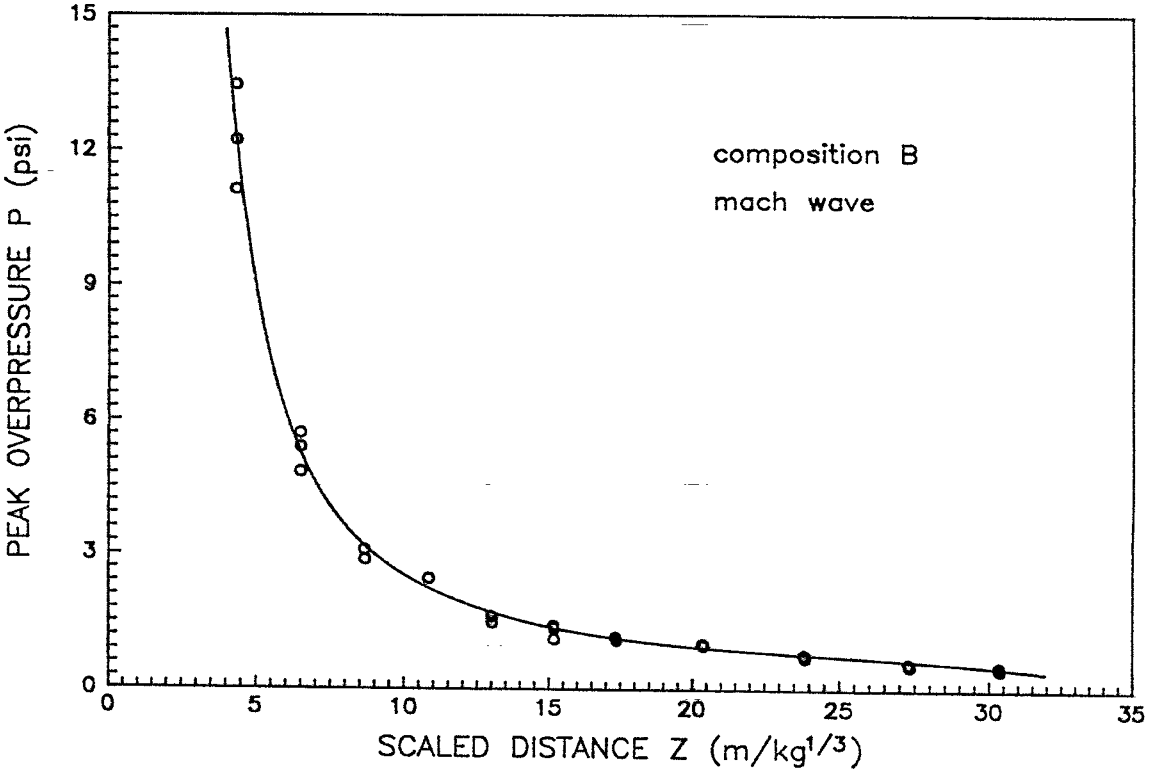

Figure 6. Overpressure as a function of scaled distance in Mach-wave region for composition B (~ 12.3 kg).

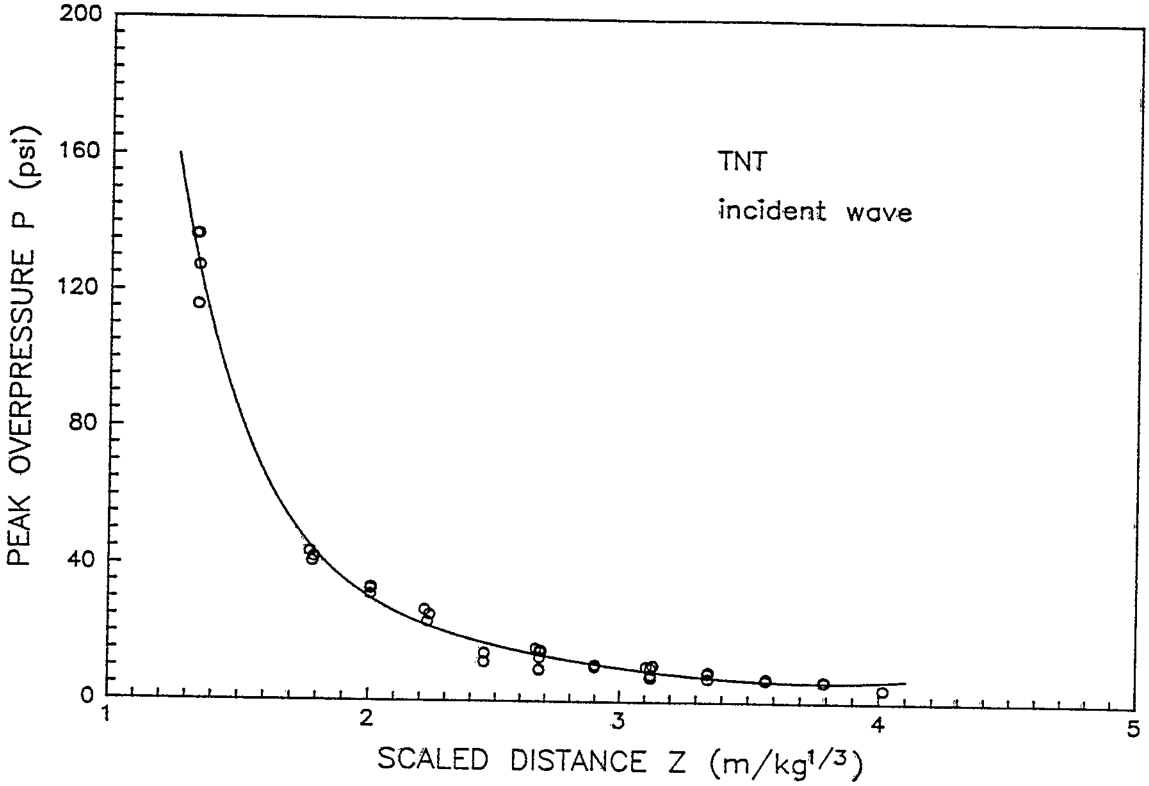

Figure 7. Overpressure as a function of scaled distance in incident-wave region for TNT (~ 11.3 kg).

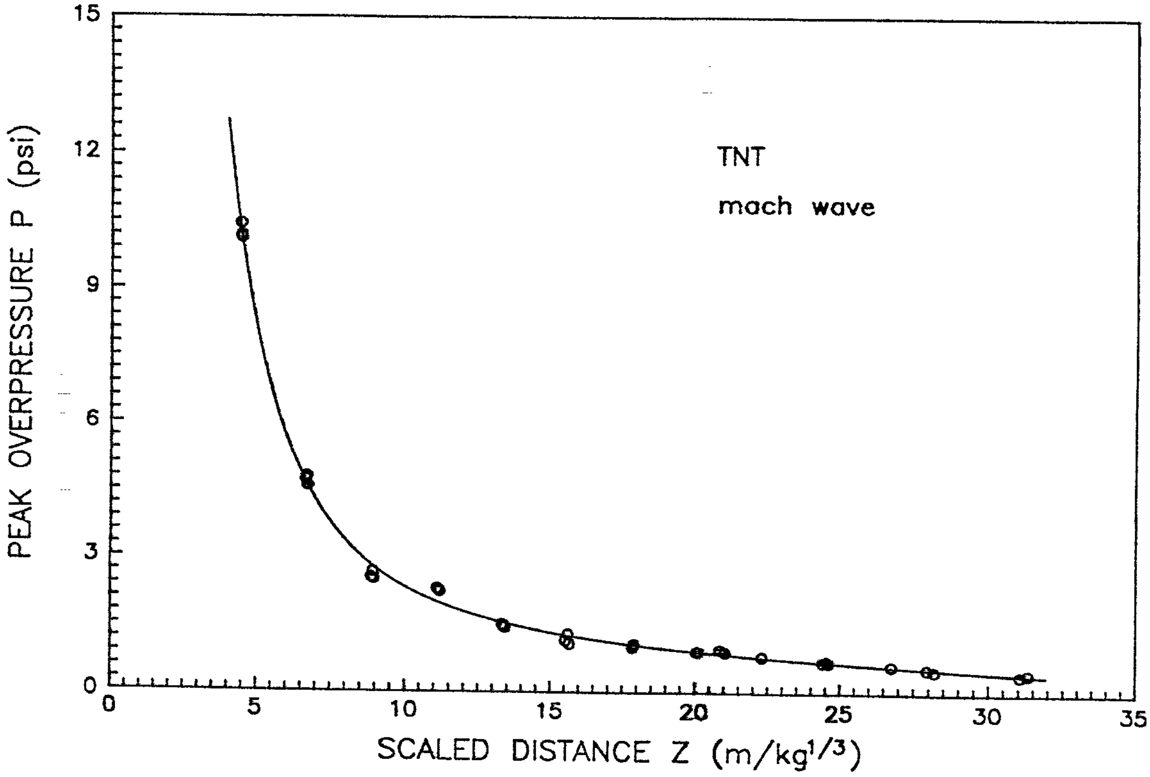

Figure 8. Overpressure as a function of scaled distance in Mach-wave region for TNT (~ 11.3 kg).

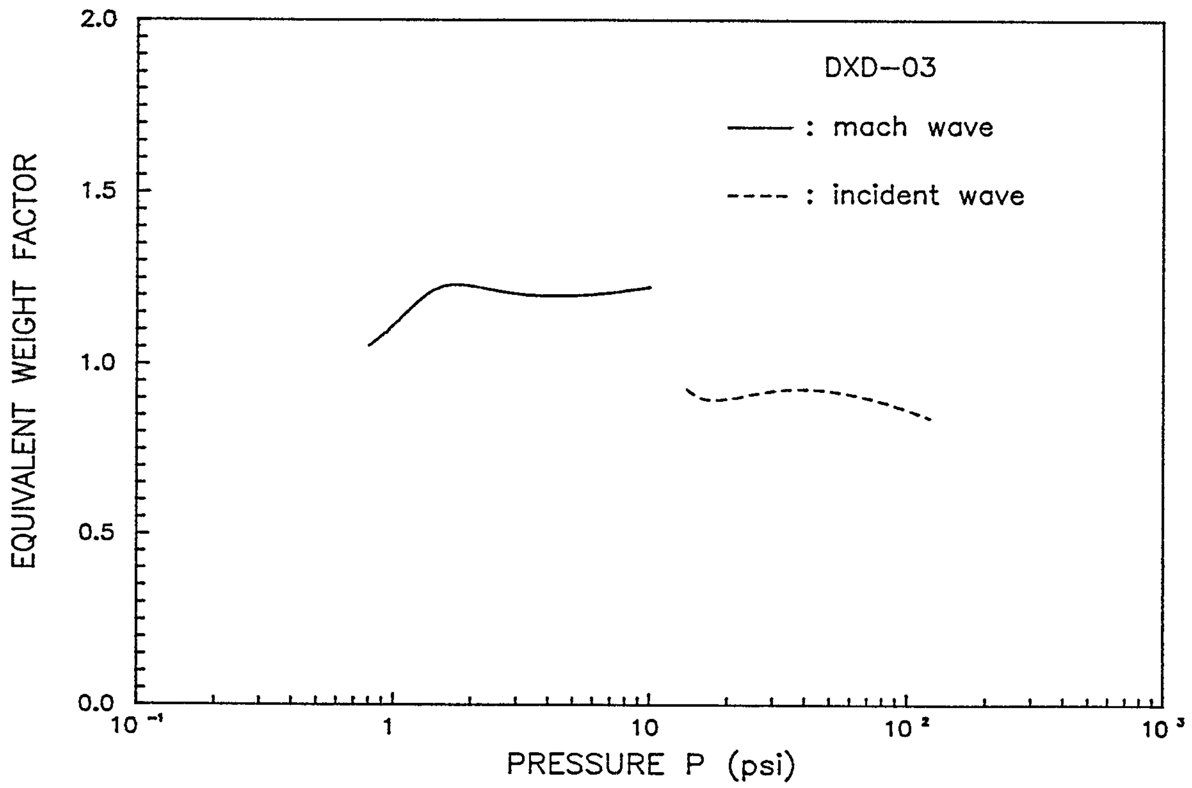

Figure 9. TNT-equivalent weight factor of DXD-03.

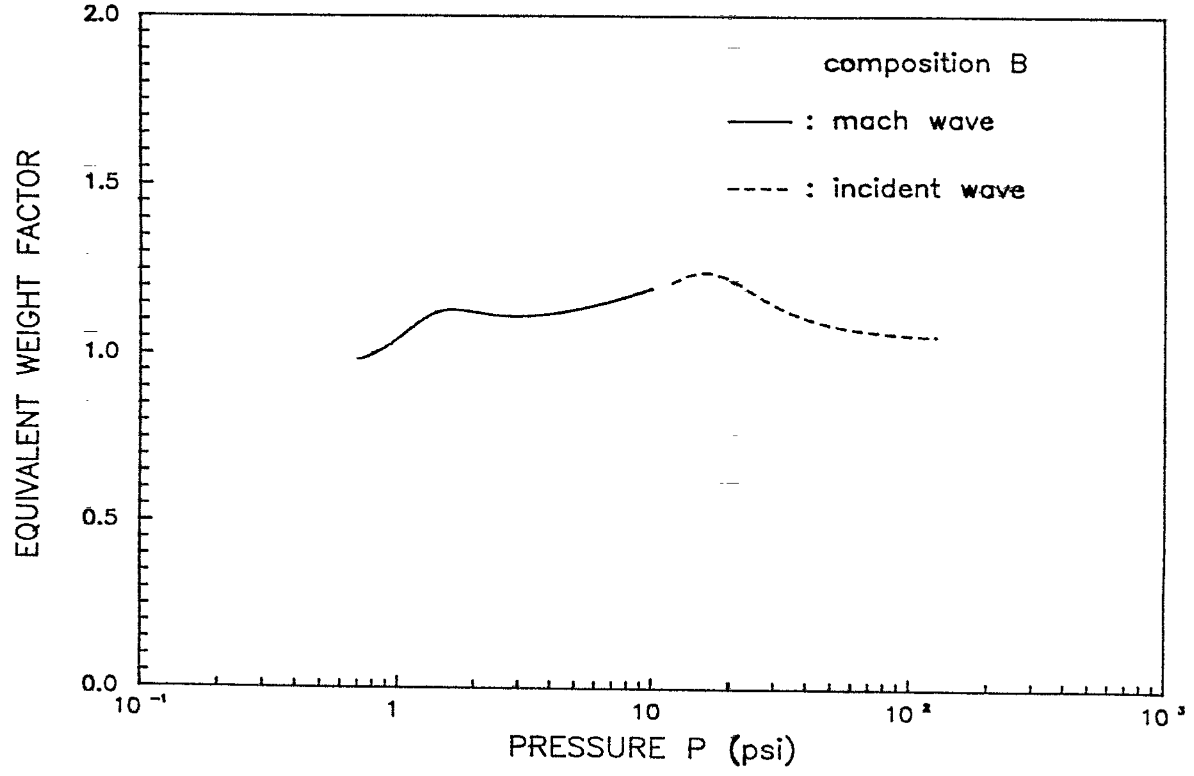

Figure 10. TNT-equivalent weight factor of composition B.

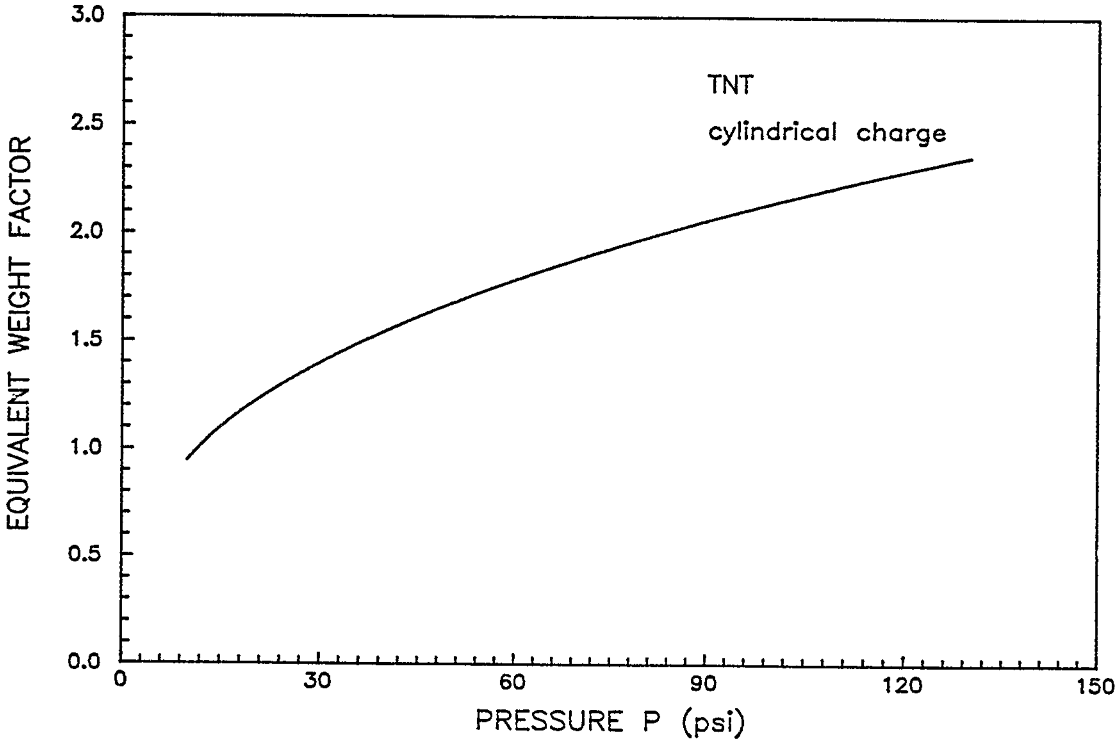

Figure 11. Geometry effect of cylindrical TNT charges (length/diameter = 1) over spherical charges.