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ENGINEERING ELEMENTS OF EXPLOSIONS

by

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ABSTRACT. Two rather distinct types of blast are generated in the ordinary atmosphere in a conventional explosion. One is a close-in composite blast that involves both explosion products and air; the other is a more remote blast that involves atmospheric air only. These two types of blast are described qualitatively and quantitatively in terms of a reference explosion, chosen here as that of a bare spherical charge of unit mass of TNT in the ordinary atmosphere. The scaling laws for explosions which are geometrically similar are deduced from basic principles, and their limitations carefully outlined. Representative applications are illustrated by numerical examples. The transient nature of blast is one of its important aspects and makes it difficult to establish its damage potential by analytic means in any except the simplest circumstances. Hence, there is still need for semi-empirical methods such as one based on critical impulse delivered within a critical time. Detailed tables for characteristics of blast from reference explosions (Appendixes A and B) give values for peak overpressure, impulse, decay characteristics, and travel and duration times, all as a function of distance and for both free-field and normal reflection situations.

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INTRODUCTION

Explosion damage is a consequence of energy transfer from explosive to target. Mechanisms for this energy transfer are afforded both by missiles and by blast, the relative importance of which depends on circumstances. Missiles such as a rifle bullet or shrapnel are effective devices for transfer of energy, particularly when a limited amount of this energy is available. For large explosions or for area targets, blast may well be a major mechanism for explosion damage, and is also of concern in distributed energy explosions and with weapons that achieve a focused blast effect. In addition, blast is important in connection with the safety aspects of explosives, with disaster recovery planning, and in any situation where protection against explosions is required.

To outline briefly the nature of blast, the sudden expansion of originally highly compressed explosion products generates the blast wave. For a conventional explosive in the ordinary atmosphere, the close-in blast involves both these expanding products and the air that they are pushing back. This air is compressed in the push-back process, and so acts to retard the expanding products and to extend the disturbance. The air portion of the blast outruns the products portions, and at some distance from the explosion the blast involves atmospheric air only. There are then two types of blast waves, those close-in that are of composite nature and involve both explosion products and atmospheric air, and those further out that involve atmospheric air only.

The two types of blast waves are conveniently described in terms of a reference explosion, chosen here as that of a bare spherical charge of TNT in the ordinary atmosphere, a situation for which there are detailed analytic calculations (Ref. 1 and 2) and confirming experiment measurements (Ref. 3-5).

DISCUSSION

SHOCK FRONT OF A BLAST WAVE

The sheath of highly compressed air surrounding the central core of expanding explosion products moves out from the explosion at supersonic speed. A pressure jump, or pressure discontinuity, marks its leading surface. This discontinuity is the shock front for the explosion. For the reference explosion, the initial jump in pressure of the surrounding atmosphere occurs at the charge surface and has a value of about 450 bars (about 6,500 psi). The intensity of this pressure jump decreases rapidly with distance out from the center of the explosion, and approaches zero for infinite distance. This pressure jump is referred to as the "peak overpressure" for the explosive blast wave.

There appears to be no simple analytic expression that adequately describes behavior of the peak overpressure with distance from the center of the explosion. However, it may be noted that the peak overpressure decreases with a maximum of eight-thirds power of the distance at moderate distances such as 20 charge radii from the explosion, and that both closer in and further out the exponent expressing the rate of decrease is smaller. At remote distances from the explosion the peak overpressure is inversely proportional to the first power of the distance. This is the behavior of a sound wave. Hence, it may be said that any explosive blast eventually degenerates into a sound wave, which is the characteristic sound of an explosion far away.

PRODUCTS-AIR INTERFACE

The tremendous unbalance between explosion pressures and those of the surrounding atmosphere serves to accelerate drastically the perimeter portions of the products of detonation. The resulting motion of this material is a primary mechanism for generation of the atmospheric disturbance. As these rapidly moving products impinge on surrounding air, their motion is impeded and their forward momentum transferred to the air. The location at which forward motion of products ceases is a basis for distinguishing between composite blast and simple air blast. For the reference explosion the distance for maximum excursion of products is about 16 charge radii, or about 95 centimeters for the explosion of 1 kilogram of TNT (2.4 feet for 1 pound). The peak air shock overpressure experienced previously at this distance is about 12 bars (about 175 psi) in the standard atmosphere. Also, the mass of air displaced by explosion products becomes somewhat more than three times the mass of the explosive.

At the interface between products and air, the pressure decreases from an initial value of about 450 bars at the charge surface down to atmospheric pressure at its maximum excursion distance. However, this interface cannot be located as definitely as this discussion implies. The expanding explosion products form a roiling cloud, and contact between products and resisting atmospheric air occurs in a turbulent interaction-transition zone rather than at an infinitely thin contact surface (Ref. 6). An important aspect of this turbulence is that it becomes difficult to assign precise characteristics to the expanding explosion products. Hence, close-in characteristics of an explosion, as quoted here or elsewhere, should be regarded as representative rather than as definitive. Furthermore, the turbulent nature of the contact zone makes the interface appear to extend further than the distances computed on the basis of sharp discontinuity. Also, explosion products from an oxygen deficient explosive such as TNT may react with oxygen from the air to produce an apparent extension of the contact zone.

PRODUCTS CLOUD

Pressure initially within the explosion products is detonation pressure. For TNT, detonation pressure is a maximum of about 177 kilobars at theoretical loading density of 1.65 g/cc, about 160 kilobars at an achievable 1.615 g/cc, or about 148 kilobars at nominal loading density of 1.50 g/cc. The central portion of this products cloud expands more or less directly in place, and here the pressure decreases in accordance with the isentropic pressure-volume relation. As this cloud expands it engulfs the immediately surrounding volume, producing pressures which may very well exceed those at that location produced by the previously passing air shock front. Direct explosion pressures exceed shock-generated pressures out to about 1.6 charge radii, where the peak is about 350 bars (about 5,000 psi) in the ordinary atmosphere. This particular distance thus distinguishes between the region of direct explosion effects and the region of blast-wave effects.

To summarize these pressure regions, direct explosion pressures in the ordinary atmosphere involve distances less than about 1.6 charge radii from explosion center and peak overpressures greater than about 350 bars (5,000 psi). The region of composite blast extends out to about 16 charge radii or more, with peak overpressures between 350 and 12 bars (5,000 psi and 175 psi). Simple air blast occurs at distances greater than this nominal 16 charge radii and shows peak overpressures less than 12 bars (175 psi) for the reference explosion in the ordinary atmosphere.

STRUCTURE OF COMPOSITE BLAST WAVES

The relatively complicated pressure structure for a composite blast wave is shown in Fig. 1. Outermost is the shock with its accompanying peak overpressure, and within it there is an air sheath surrounding the explosion products. Next is a layer of recompressed explosion products that have been decelerated by impact with the air sheath. Within this is a zone of rapidly moving products at a lower pressure, and then a centrally located products cloud. For the particular time shown in Fig. 1, the air shock (S_1) is at a distance of 5 charge radii from explosion center. The contact surface or products-air interface, (C.S.), is at about 4.6 charge radii, and the shock-wise deceleration (S_2) of products impinging on previously decelerated layers, the so-called second shock, is just within this distance.

Figure 2 shows profiles for additional items at this particular time. Discontinuities at both the air shock and the second shock are shown in

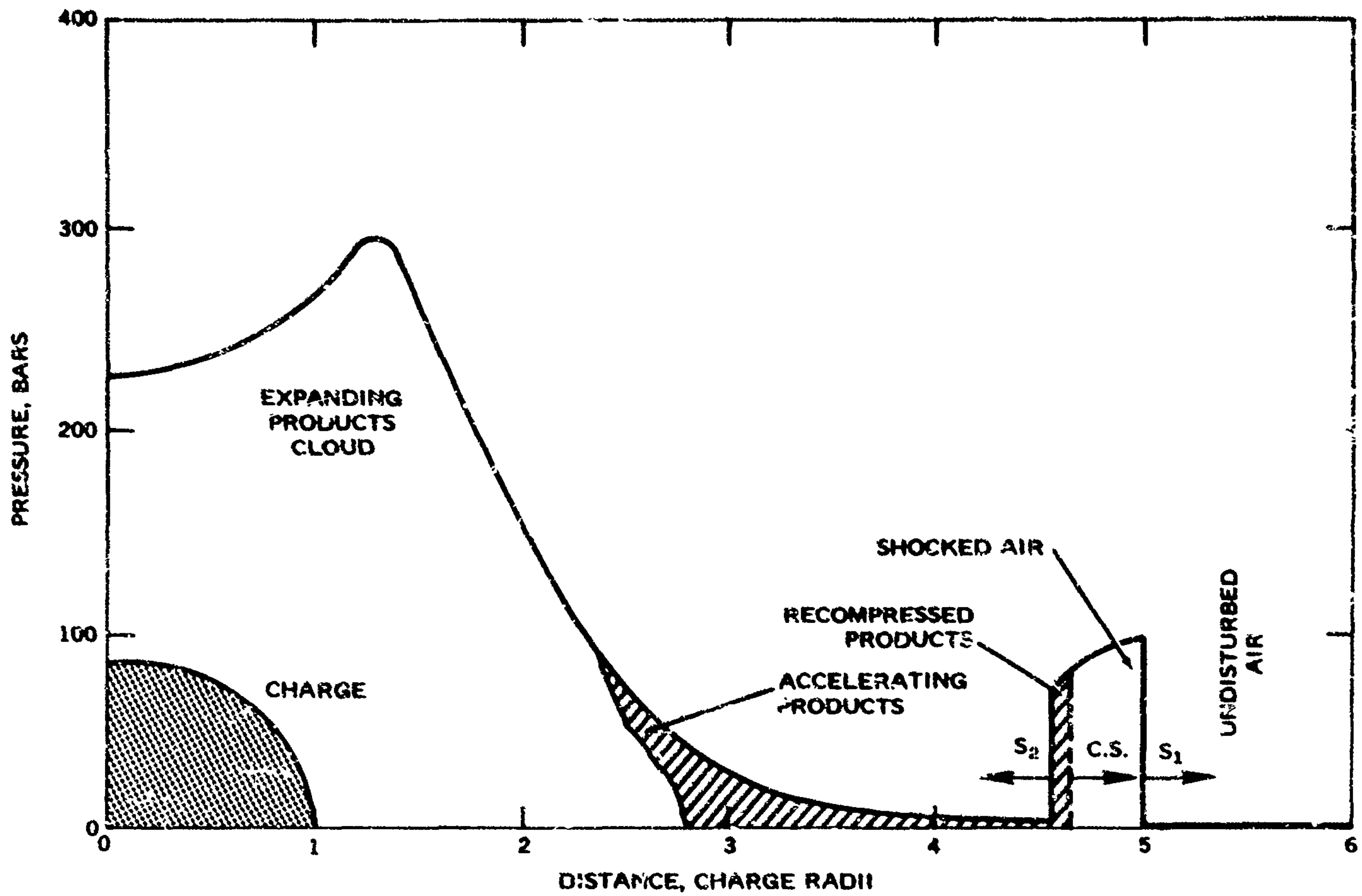


FIG. 1. Pressure Profile When Shock Front is at 5 Charge Radii.

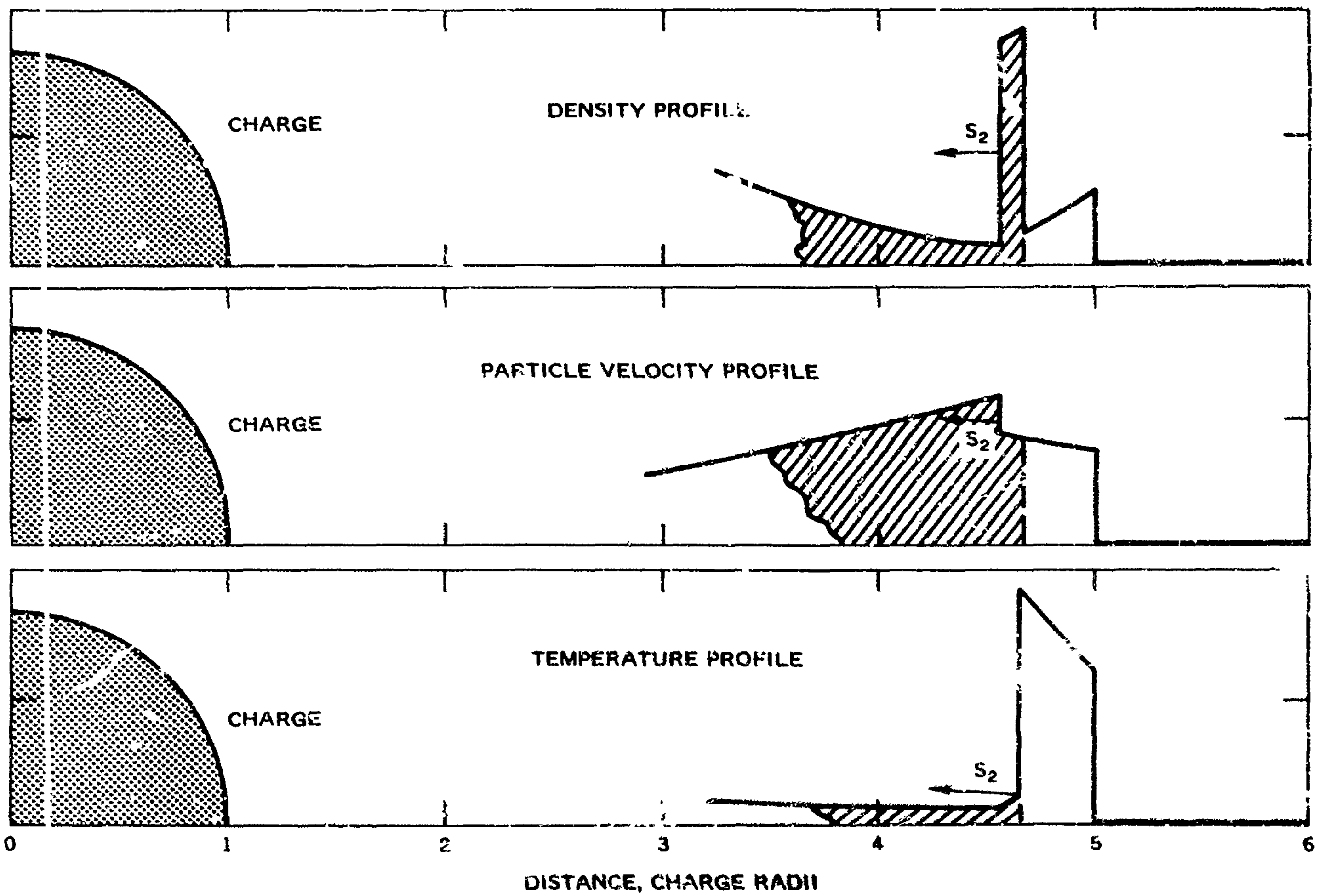


FIG. 2. Density, Particle Velocity, and Temperature Profiles.

all these profiles. However, the profiles for the pressure and particle velocity exhibit continuity at the products-air interface and only the temperature and density profiles show discontinuity. (The computations which provide the data for these profiles have made suitable allowance for both nonideal gas behavior and for variation of specific heat with temperature.)

BLAST-WAVE DURATION

The pressure profile for a composite blast reaching out to 11 charge radii from explosion center is shown in Fig. 3. At this time pressures in the central products cloud have become less than those generated at the shock front. Worded alternatively, rarefaction has progressed back through the explosion products. Also at this time a negative pressure phase, one with pressures less than atmospheric, appears inward of the second shock in the accelerating products.

Appearance of a negative pressure at any location limits the time duration for the positive pressure phase. For the reference explosion this negative pressure appears first at a distance of about 9 charge radii from explosion center and so this distance also marks the location of a minimum time duration for the positive phase. Closer in, pressures in the products cloud persist for longer than minimum time, and further out the air sheath is thicker and travels slower, hence its positive pressure at a given location persists for a longer time.

Precise values for a duration of the positive pressure phase of any explosive blast (and its negative phase as well) are rather difficult to establish experimentally. Close in, the turbulent nature of the products cloud reduces the significance of any individual value, and further out a slow pressure subsidence of the less intense blast waves allows inherent random fluctuations to obscure the measurements.

AIR BLAST FROM AN EXPLOSION

The pressure profile for a blast-wave system that extends out to 25 charge radii from explosion center is shown in Fig. 4. At this particular time the explosion products have reached their maximum calculated excursion of 16 charge radii, and the pressure at the products-air interface is now atmospheric. Pressures within the products region, including those generated in the second shock, are now all less than atmospheric. Pressures in the air sheath extending from air-products interface out to the shock front are all above atmospheric, and form a region of positive overpressure with relatively simple structure.

The pressure profile for the blast wave when the shock front disturbance has reached still further out to 50 charge radii is shown in Fig. 5.

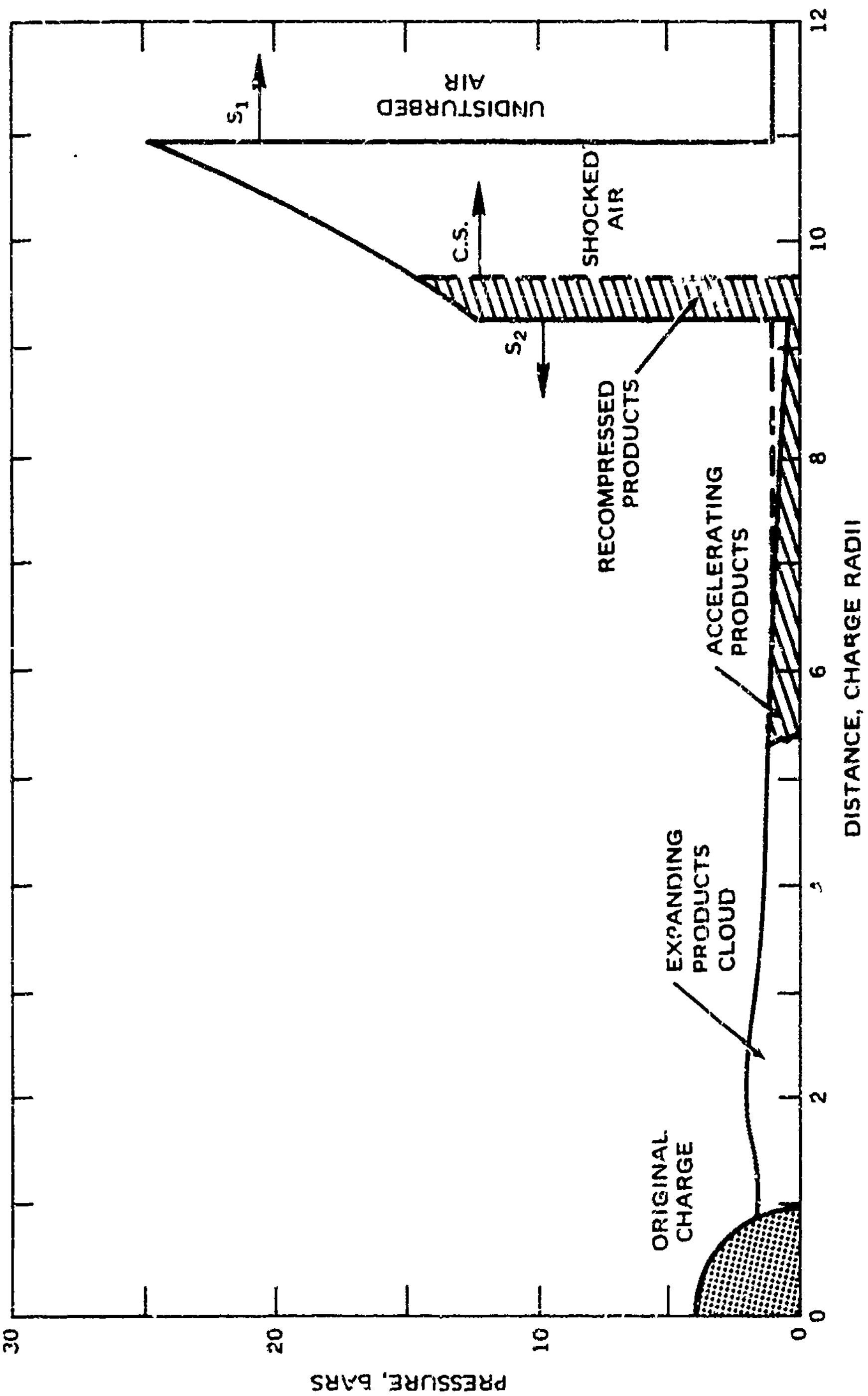


FIG. 3. Pressure Profile When Shock Front is at 11 Charge Radii.

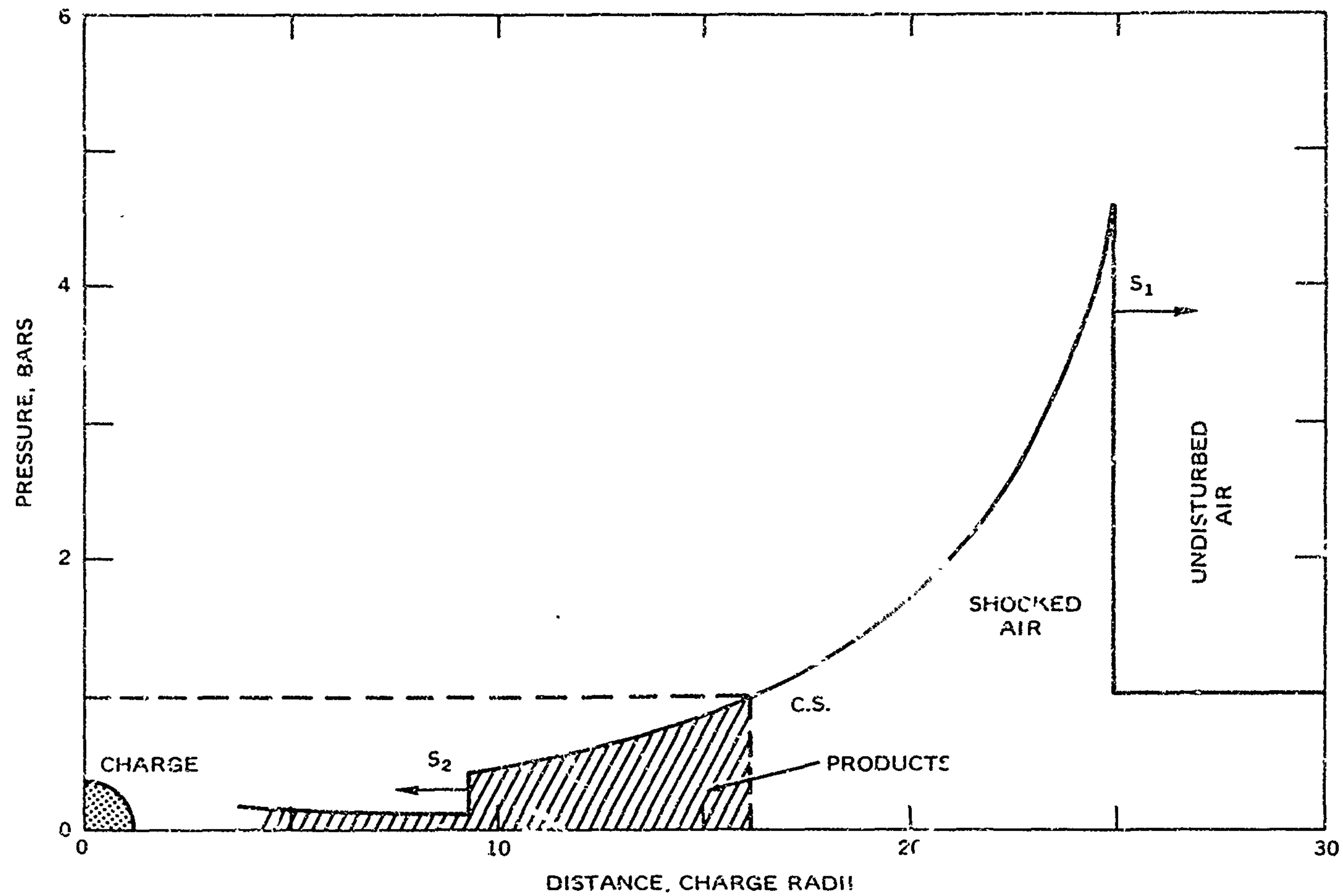


FIG. 4. Pressure Profile for Shock Front at 25 Charge Radii.

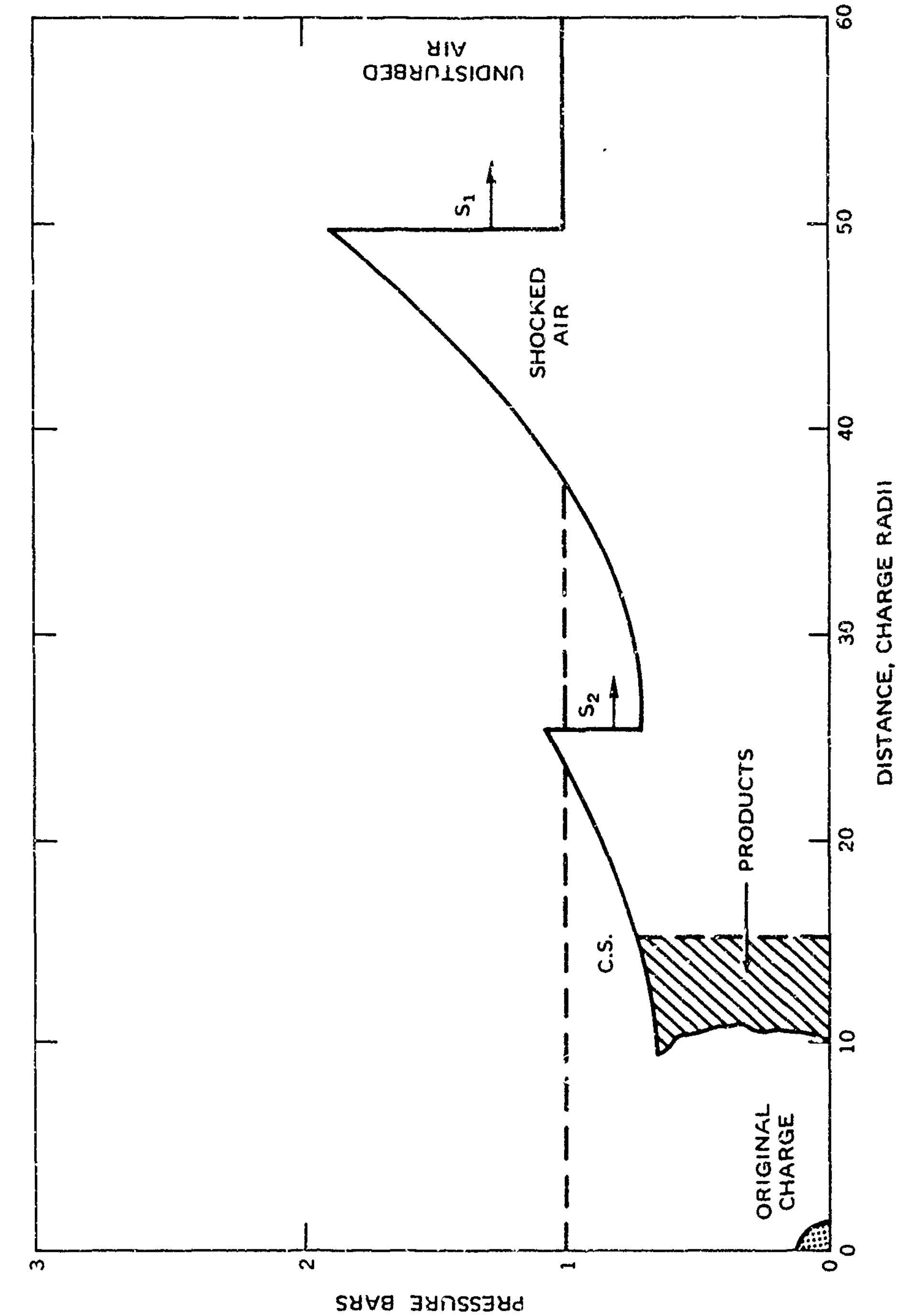


FIG. 5. Pressure Profile for Shock Front at 50 Charge Radii.

Here, also, the initial positive pressure phase involves only air from the atmosphere and the air blast is relatively simple in structure. Closer in, where both products and air are involved, the situation is more complex. The second shock by now has retreated to explosion center and been reflected back by the consequent implosion. Passing through the products-air interface, the density discontinuity and associated impedance mismatch at that interface causing a rarefaction disturbance, and following shock, move inward through the products. This shock then implodes at the center, etc., and these processes repeat until all the explosion energy has been dissipated. The magnitude of these supplementary shocks is small, and is further diminished by turbulence in the products cloud. These complex effects thus have little damage potential and ordinarily are disregarded in blast-damage studies.

Figure 6 is a summary, to log-log coordinates, of the pressure-distance relations for air-shock front, the products-air interface, and for the direct pressures of the expanding products cloud, all for the reference explosion. It also indicates the pressure-distance contours for several successive times t_1, t_2, t_3, and t_4 after the instant of explosion.

TIME-OVERPRESSURE RELATIONS FOR AIR BLAST

Related to the pressure-distance relations for a given time after explosion is the overpressure-time relation at a given location, for this pertains directly to blast damage potential and to experimental blast-wave measurements. A typical overpressure-time relation for a specified distance is shown in Fig. 7. This is for the free-field overpressures at various times at a distance of about 25 charge radii from the reference explosion. Its peak overpressure is 3.6 bars, and for a 1-pound charge of TNT this occurs about 0.8 milliseconds after the instant of explosion. The overpressure then decays to zero in a duration of about 0.70 milliseconds additional time (for this charge). For comparison with this theoretically calculated curve, Fig. 8 shows two actual overpressure-time records (but not to the same scales).

The relatively simple structure of these blast waves permit their description in terms of simple numbers. General appearance suggests an exponential relation, but the overpressure goes negative in finite time, a behavior not accommodated by a simple exponential. An empirical adjustment is readily made, however, to give a relation that adequately describes the positive overpressure phase of the air blast. This gives

$$p = p^o(1 - t/t_d)e^{-bt/t_d} \tag{1}$$

where p is the overpressure at time t which decays from its peak value p^o at zero time to zero value at duration time t_d. The item b, the decay

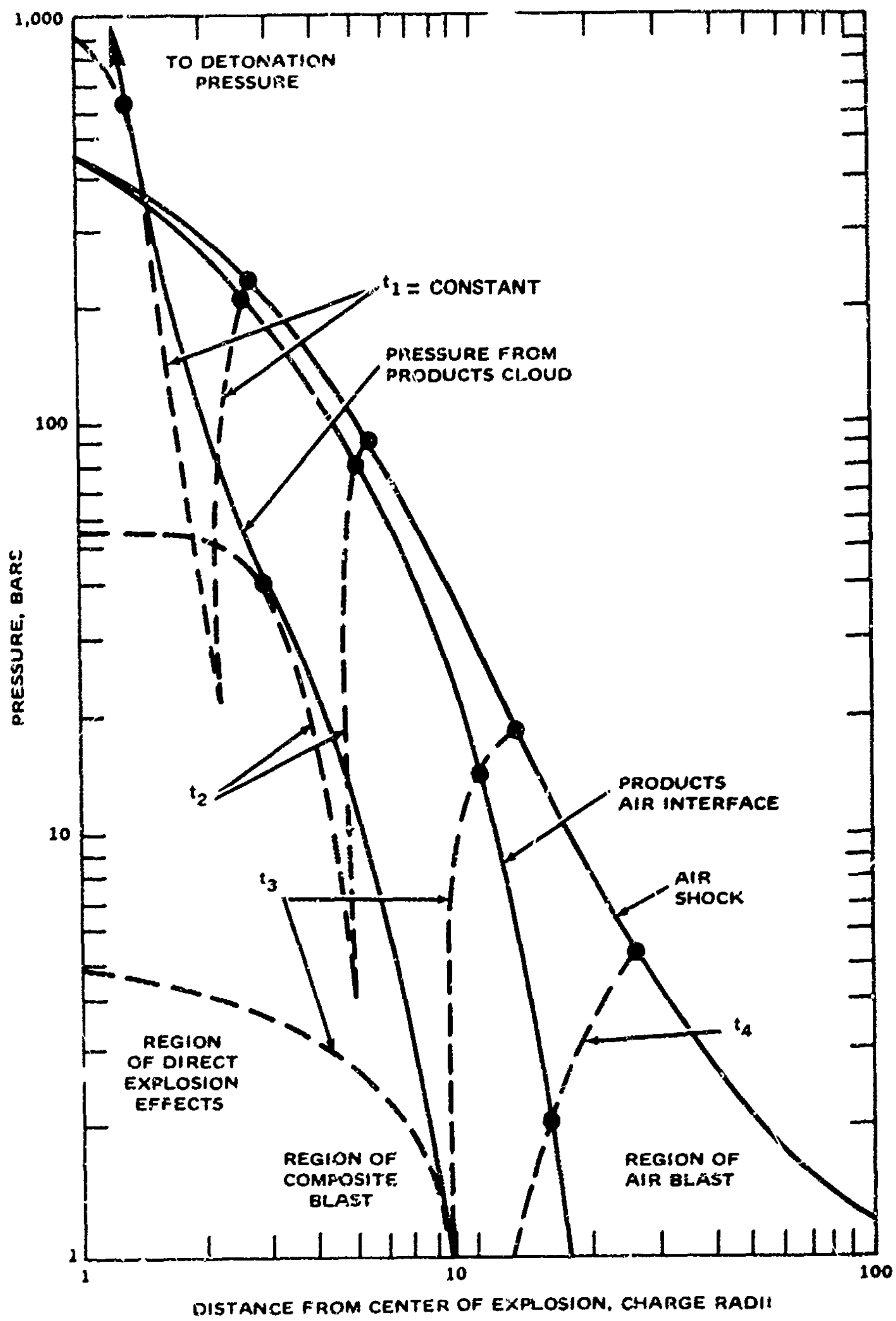


FIG. 6. Pressure-Distance-Time Relations for Reference TNT Explosion.

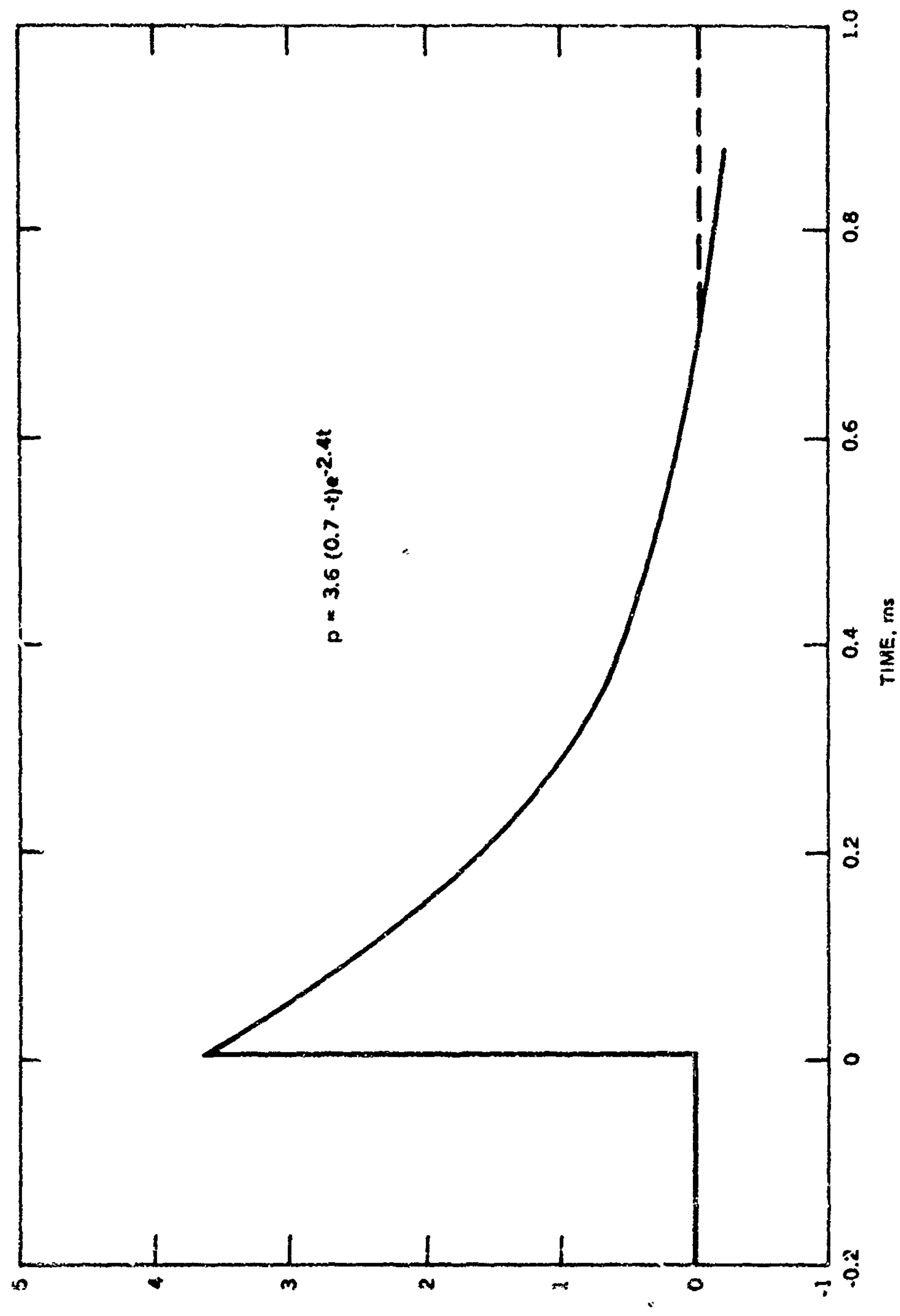
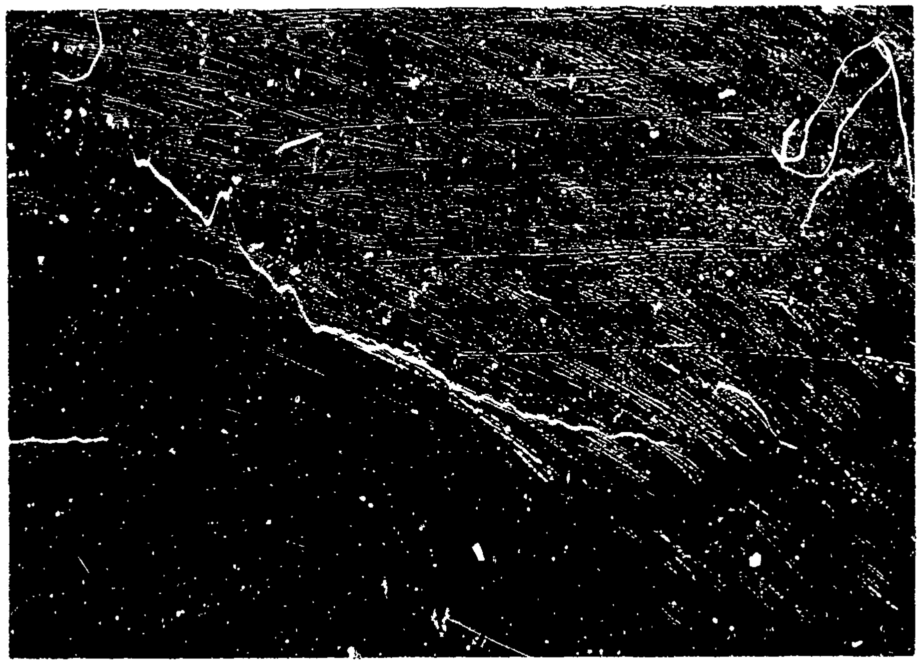


FIG. 7. Time-Overpressure Relations for Representative Simple Air Blast.



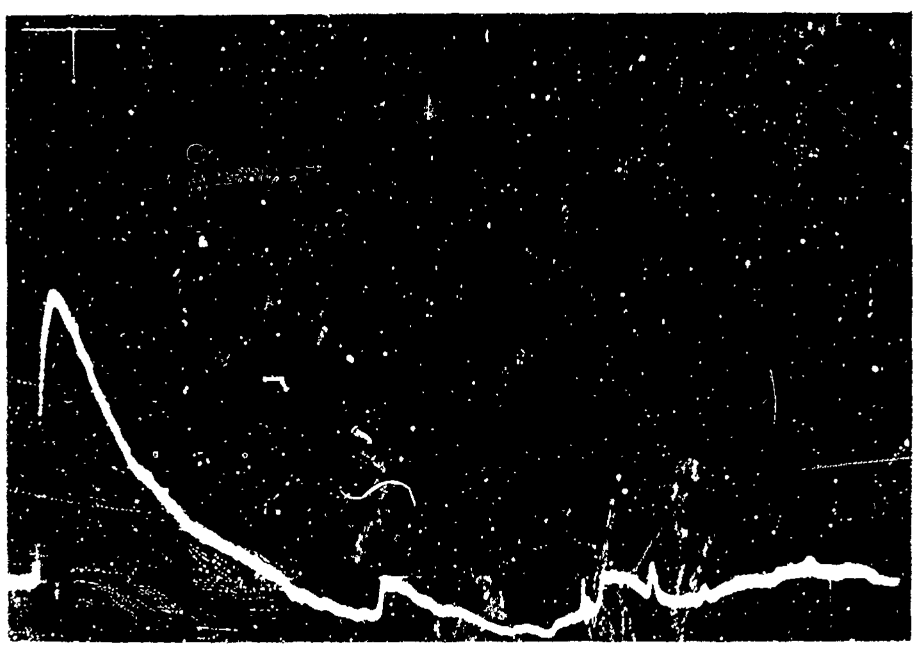


FIG. 8. Actual Overpressure-Time Records. Upper record is with high impedance gage; lower with low impedance gage.

parameter, is analogous to a rate constant. Its value varies with distance from the explosion, decreasing from a maximum of about 4.17 at the nominal 16 charge radii marking the beginning of simple air shock down to a value of about 0.9 at around 40 charge radii. It decreases to still lower values at more remote distance as the blast wave becomes distorted with distance and presumably approaches the triangular at the more remote distances. The triangular blast wave corresponds to zero decay parameter; it is of interest to note that much of the earlier theoretical work on blast assumed a triangular blast wave. Currently, for an approximation, the value unity is assigned to the decay parameter for all distances; the insensitive nature of the relation makes this a quite acceptable approximation for many purposes.

The analysis of measured time-overpressure relations and the assignment of values to the decay parameter are considered later. However, note that the dimensionless nature of the decay parameter b of Eq. 1 makes its values apply directly to all the various systems of units used in blast-wave studies.

For the close-in composite blast wave there is no simple analytic expression for its time-overpressure relation, and any expression such as the above is at best only an approximation. This composite shock not only involves two materials, products and air, but also pressure discontinuities such as the second shock, and here a graphical presentation of shock characteristics is indicated.

BLAST IMPULSE PER UNIT AREA

The impulse characteristic of a blast wave is the total momentum charge per unit area of blast surface. It is an important parameter in the study of blast damage potential. The positive impulse per unit area is given as the time integral of the (positive) blast overpressure. For simple air blast, where the positive overpressure-time relation can be described analytically by Eq. 1, this integration provides

$$\underset{\text{(per unit area)}}{\text{impulse}} = \int_0^{t_d} p\, dt = p^o t_d\, [(1/b) - (1-e^{-b})/b^2] \qquad (2)$$

For the blast wave shown above, with peak overpressure 3.6 bars, duration 0.70 milliseconds, and decay parameter 1.7, the positive impulse per unit area is computed by Eq. 2 as 0.077 bar-milliseconds.

Impulse characteristics are ordinarily included as part of the complete description of a blast wave, for example the 0.077 bar-milliseconds (Fig. 7) above. In addition to such direct specification there are available two alternative indirect methods. One is through the decay parameter, for in Eq. 2 this defines the impulse when peak overpressure and time duration are known. The other indirect method is as a fraction of the square-wave impulse value (product of peak overpressure and duration). This indirect item is also dimensionless, and in the instance above this fraction is about $0.077/(3.6 \times 0.7) = 0.30$. This fraction varies from a minimum of about 0.17 for the rapidly decaying wave formed at the demarcation between composite blast and air blast where decay parameter b equals about 4.7, up to a limiting value of one-half for remote distances where the blast wave approaches the triangular as the decay parameter approaches zero. Values for these and other impulse factors have been completed and are listed below. Of these two alternative methods for describing the impulse of a blast wave, the one in terms of decay parameter has the advantage over the fraction of square waves impulse in that the decay parameter also specifies the entire time history for the positive overpressure phase. This provides additional information useful in a detailed study of target interaction and damage potential of the blast.

Decay parameter b	Fraction of square-wave impulse value
0.0	0.500
0.2	0.468
0.4	0.440
0.6	0.413
0.8	0.390
1.0	0.368
1.2	0.348
1.4	0.330
1.6	0.313
1.8	0.298
2.0	0.284
2.5	0.253
3.0	0.228
3.5	0.207
4.0	0.189
4.5	0.173
5.0	0.160

The impulse characteristic of composite close-in blast is much more complex than that for simple air blast. For example, at distances of about 10 charge radii from the TNT explosion the free-field impulse of the composite blast actually increases with increasing distance. Direct values for the close-in impulse per unit area obtained by time integration of the complex overpressure-time relation can be expressed simply in dimensionless form as a fraction of the square-wave impulse value. For composite blast this fraction decreases from about one-half at the charge surface down to a minimum of about 0.06 at about 3 charge radii, goes through a maximum of nearly one-half at the distance for minimum blast duration, and then decreases down to about 0.17 at the 16 charge radii that marks the maximum excursion of explosion products.

REFERENCE EXPLOSIONS

Nominal values for the various characteristics of arbitrarily selected reference explosions are given in Appendixes A and B. Appendix A is based on the explosion of 1 kilogram of TNT in ordinary air at a temperature of 15 Celsius (59°F) and a pressure of 1 bar. Appendix B is for the explosion of 1 pound of TNT in air at 59°F and 13.6 psia (typical conditions for this Center). These values tabulated for reference explosions can be applied to realistic situations by means of the scaling laws as described below.

SCALING LAWS FOR EXPLOSIONS

Scaling laws for explosions are based on the principle of geometrical similarity and on the observation that the spatial dispersion of explosion energy is a volume effect. Thus doubling a distance from an explosion increases the volume of medium affected by a factor of eight, hence eight times the explosion energy (explosive yield) is required to achieve a similar blast. To allow also for the influence of the nature of the surrounding medium on this energy dispersal, note that the transfer of momentum from expanding explosion products to surrounding medium is a mass effect. Hence, energy release per unit mass of surrounding medium is a controlling item. In this study, atmospheric density is used as a measure of the relative mass of the atmospheres in which explosions may occur.

To apply these concepts, define a "scaled distance" as the equivalent distance from a reference explosion, one that corresponds to some actual distance from some actual explosion. From basic considerations

$$\frac{(\text{scaled distance})^3 \times (\text{reference atmospheric density})}{(\text{reference yield})}$$

$$= \frac{(\text{actual distance})^3 \times (\text{atmospheric density})}{(\text{actual yield})} \tag{3}$$

Representing the yield as W and atmospheric density as ρ, and with subscript o to identify the reference explosion, Eq. 3 can be rewritten as

$$\text{scaled distance} = \frac{(\text{actual distance}) \times (\rho/\rho_o)^{1/3}}{(W/W_o)^{1/3}} \tag{4}$$

or for the ordinary atmosphere at absolute temperature T and absolute pressure P

$$\text{scaled distance} = \frac{(\text{actual distance}) \times (P/P_o)^{1/3}}{(W/W_o)^{1/3} \times (T/T_o)^{1/3}} \quad (5)$$

By an analogous sort of reasoning, it may be shown (Ref. 7) that the scaled distance as so defined also carries within it a definition of scaled time. That is

$$\text{scaled time} = \frac{(\text{actual time}) \times (\rho/\rho_o)^{1/3} \times (a/a_o)}{(W/W_o)^{1/3}} \quad (6)$$

where a represents the speed of sound in the actual atmosphere and a_o that in the reference atmosphere. In the atmosphere, this speed varies with the square root of the absolute temperature, so that Eq. 6 may be rearranged to give

$$\text{actual time} = \frac{(\text{scaled time}) \times (W/W_o)^{1/3}}{(P/P_o)^{1/3} \times (T/T_o)^{1/6}} \quad (7)$$

The impulse characteristic of a blast wave, that is, its positive impulse per unit area, also follows the scaling laws. Defining scaled impulse as the value for a reference explosion and actual impulse as that for some other amount of explosive in some other atmosphere, the two are related as

$$\frac{\text{actual impulse}}{\text{scaled impulse}} = \frac{\text{actual time}}{\text{scaled time}} \times \frac{\text{actual ambient pressure}}{\text{reference pressure}} \quad (8)$$

Expressed symbolically, and combining with Eq. 7

$$\text{actual impulse} = \text{scaled impulse} \times \frac{(W/W_o)^{1/3} \times (P/P_o)^{2/3}}{(T/T_o)^{1/6}} \quad (9)$$

These definitions of scaled distance, time, and impulse involve ratios of absolute values for atmospheric pressure and temperature raised to a fractional power. In many circumstances this gives numerical values that do not differ greatly from unity. When one considers the considerable uncertainty in measurements on any actual explosion, it becomes apparent that these ratios often may be taken as unity without introduction of additional error. This makes for a desirable simplification in formulas for the scaling laws. Furthermore, measure explosive yield in relative rather than in absolute terms such as the energy release implied above. That is, our reference explosive yield can be that of unit mass of some reference explosive. As a reference explosive, TNT has desirable aspects of being reproducible, relatively safe, inexpensive, and readily available in calibration amounts. The value for the reference yield W_o then becomes unity, and value for the actual yield W becomes its TNT equivalent.

In these circumstances,

$$(\text{actual distance}) = (\text{scaled distance}) \times W^{1/3} \tag{10}$$

$$(\text{actual time}) = (\text{scaled time}) \times W^{1/3} \tag{11}$$

$$(\text{actual impulse}) = (\text{scaled impulse}) \times W^{1/3} \tag{12}$$

where W is effective yield in terms of the equivalent amount of TNT for the explosive whose explosion is being studied. Equations 10-12 should be regarded as merely convenient approximations for the primary forms of the scaling law as in Eq. 3, 6, and 8. Various aspects of these scaling laws are illustrated by numerical examples in the calculations of Appendix C.

LIMITATIONS OF SCALING

It is to be emphasized that the scaling laws, both in original and in approximate forms, have been deduced on the basis of explosions with geometrical similarity. That is, these scaling laws apply to explosions related to each other as a photograph is related to its enlargement. Thus, in general, data on a free-field reference explosion cannot be expected to apply directly to a blast wave which has undergone the complicating effect of interaction with a ground surface, nor can a free-field explosion be scaled to one which gives shock reflections or Mach stem formation. Furthermore, there is also the requirement that two explosions to be compared must occur in atmospheres of the same general nature. Thus the scaling laws cannot be used to apply data for a reference explosion, in the ordinary atmosphere to an underwater one, nor to an exoatmospheric explosion of outer space. But on the other hand, most conventional explosives have about the same charge density, the same energy release, and generate about the same volume of gas per unit mass of explosive. Thus, ordinary explosions may actually meet the scaling law requirements of geometric similarity in many circumstances.

For nuclear explosions, both charge radius and products excursion distance are very small and quite different from those for a TNT reference explosion with the same energy release. Hence, these close-in effects do not scale to TNT. But for remote distances, the blast wave from either a nuclear or conventional explosive involves air only and each has the same general behavior. An empirical adjustment can bring these two air blast waves into general conformity. Such an adjustment indicates that the effective energy release in a nuclear explosion is about 85% the actual energy release.

Another instance of interest is the explosion of a gaseous mixture, for example that of methane and air. Lack of geometrical similarity between the large charge size of a gaseous explosive and the small charge size of relatively dense TNT means that TNT is hardly a suitable reference for gaseous explosives at close-in distances. However, at remote distances where only air blast is of concern, TNT might well suffice as reference.

Nonspherical explosions are not readily scaled to a reference spherical charge of TNT, an observation of importance in the study of focused blast explosions and in the study of blast from many types of distributed energy explosions.

For explosions in the atmosphere at high altitudes the maximum excursion of explosion products is relatively much greater than for explosions at sea level. Here the basic requirement for geometrical similarity may not be met, even for two charges of the same explosive. Hence at the very high altitudes the scaling law must be used with reservation, particularly when within the region of composite blast.

For an explosion in contact with a plane unyielding surface, the explosion energy is released into a hemisphere rather than into a sphere. Hence these blast waves may be equivalent to free-field waves generated with twice the energy release. Similar considerations apply to those special shock tubes where the explosion energy is concentrated into a small portion of a sphere. This gives a corresponding magnification of effective explosion yield, provided of course that the requirements of the scaling laws are otherwise met.

SCALING LAW YIELDS

An interesting application of the scaling laws for explosions is inverse of the one implied above. Here an equivalent yield from some actual explosion is computed from the characteristics of the blast wave it produces. This technique is illustrated in Appendix C. In general, the calculation first establishes a scaled distance from some characteristic of the blast wave such as its overpressure, speed of its shock front, or its positive impulse per unit area. Then by Eq. 5

$$\frac{\text{calculated yield}}{\text{reference yield}} = \left(\frac{\text{actual distance}}{\text{scaled distance}}\right) \times \frac{(P/P_o)}{(T/T_o)} \qquad (13)$$

For the special circumstance that reference and ambient pressures and temperatures do not differ greatly, and where the reference explosion corresponds to unit yield, Eq. 13 reduces to the simple relation

$$\text{calculated yield} = \left(\frac{\text{actual distance}}{\text{scaled distance}}\right)^3 \tag{14}$$

as illustrated in the calculations.

There are some cautionary observations to be made about calculated yield values obtained from Eq. 13 or 14. One is that the calculation involves the cube of a ratio, and this magnifies any inherent uncertainty by a factor of three. Thus these calculations are inherently of low precision. Furthermore, the yield value obtained is basically one for a spherically symmetrical explosion. Thus, it is to be anticipated that calculated values for the yield of an actual explosion may vary and depend on the type of data used in the calculation. Nevertheless, the data provide useful information for evaluation studies even if the requirements for geometrical similarity with a reference explosion are not met. This is the situation in many instances of interest such as a distributed energy explosion and focused blast. These items and calculations are in need of investigation.

EXPERIMENTAL BLAST MEASUREMENTS

Experimental measurements on blast waves are extraordinarily difficult to make (Ref. 8). They require highly sophisticated instrumentation along with utmost care in calibration and measurement. Furthermore, ingenuity and technique are required in order to avoid spurious effects such as unanticipated reflections from the earth's surface, from the formation of a Mach stem, or from some interaction between blast wave and supporting fixtures for measuring instruments. Indeed, blast measurements are so troublesome that any individual value is always suspect. This also applies even to complete sets of measurements if all are made with the same instrumentation using the same technique. Only in individually calibrated and independently made duplicate, triplicate, or replicate measurements can full reliance be placed, and even so the inherent uncertainties should be recognized. But within such limitations the experimental measurements on blast waves from spherical charges conform quite well with data on TNT explosions as given in Appendixes A and B and as scaled up (or down) in accordance with the scaling laws.

Even with adequate instrumentation and proper calibration, any particular setup almost always involves some sort of choice or compromise. One common choice is between an instrument that is stable and reliable but slow in response, and one with a fast rise time capability but which may overshoot and be sensitive to extraneous noise. Figure 8 shows (but not to the same scale) actual pressure records from these two types of of blast gages for the same blast wave. The lower record was obtained with a low impedance but stable pressure gage. Its reading for the instantaneous initial peak overpressure seems too low. The upper record is with a high impedance gage with considerably faster response. Here the initial peak seems well recorded, but some overshoot may be present and the entire record seems to be a noisy one.

To minimize these particular gage problems, a systematic method of smoothing experimental curves suitable for the special case of a simple overpressure-time relation without a multiple peak or incidental negative pressure portions has been suggested. This involves two semilogarithmic plots. One, for the early times of the blast, is the logarithm of the overpressure versus the time. Here back extrapolation to zero time gives a reliable value for the initial peak overpressure (see Fig. 9). The second plot is of the overpressure at later times versus the logarithm of the time, as in Fig. 10. The resulting compression of the time scale makes the curve approach linearity and permits a good estimate of the duration time for the overpressure as the time when the curve intersects the overpressure axis.

In addition to providing a smoothed value for peak overpressure and duration, the two semilogarithmic plots also establishes the decay parameter of Eq. 1. For this, note that the term $(1 - t/t_d)$ of Eq. 1 approaches e^{-t/t_d} as time t approaches zero. That is, at early times Eq. 1 reduces to

$$p = p^o e^{-(1 + b)t/t_d} \quad (\text{as } t \to 0) \tag{15}$$

Taking logarithms, then

$$\ln p = \frac{-(1 + b)}{t_d} t + \text{constant} \quad (\text{as } t \to 0) \tag{16}$$

Comparing Eq. 16 with the formula for a straight line, it can be seen that the slope of the semilogarithmic plot of overpressure (base e value) versus time is the negative value of the item $(1 + b)/t_d$. Equating and solving for decay parameter b,

$$b = -(\text{slope}) \times t_d - 1 \tag{17}$$

That is, measuring the intercept and slope of the plot of Fig. 9 and the intercept on the plot of Fig. 10 provides values for peak overpressure, the duration, and decay parameter. With these data the entire overpressure-time curve can be reconstructed mathematically and compared with the original measurements to provide a check on the analysis.

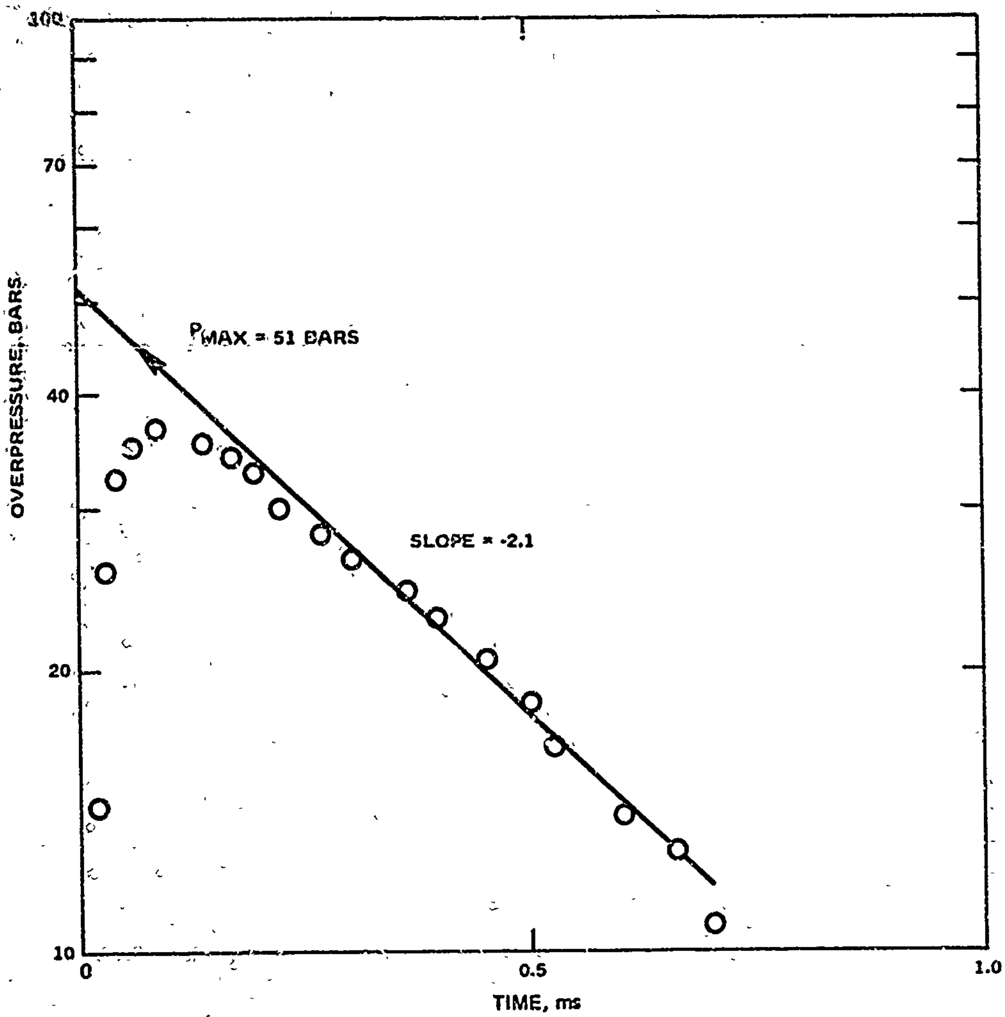


FIG. 9. Log Overpressure Versus Time. Indicated peak, 51 bars; measured peak, 38 bars. Slope is -2.1 per millisecond.

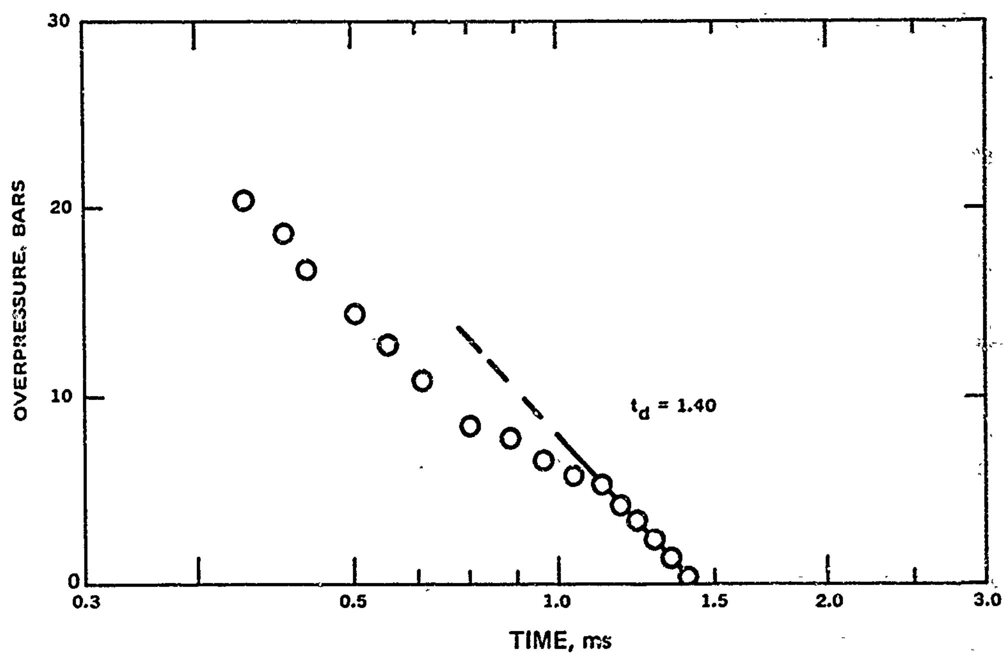


FIG. 10. Log Time Versus Overpressure. Duration 1.40 ms, decay parameter = 1.40 x 2.1 - 1 = 1.94.

A further check on the instrumentation and on the overall propriety of this analysis of experimental data is provided by values computed for the impulse. It has been observed that directly measured impulse values, as obtained by graphical or numerical integration of the overpressure-time curve, are relatively immune to response time and noise errors. If the value for the impulse as calculated using the decay parameter agrees with the directly measured value it suggests that a reasonably reliable record of the explosion has been obtained.

DYNAMIC PRESSURE FOR A BLAST WAVE

A requirement for target damage is interaction between blast and target. One interaction effect is described by the dynamic pressure q, defined as $q = 1/2\ \rho u^2$, where ρ is the density of the moving stream and u its velocity. For air, the dynamic pressure may be expressed alternatively as $q = 1/2\ k M^2 P$, where k is the specific heat ratio, M the Mach number for the moving stream, and P its absolute pressure. The dynamic pressure, when multiplied by a drag coefficient for some particular object, gives the drag force per unit area exerted by the moving stream on that object.

Dynamic pressures are important in steady-flow situations such as aircraft propulsion or flight of missiles. They are also of interest in some blast situations, for example a water tank subjected to the blast wind of a nuclear explosion. But for ordinary explosions the time duration of the blast wind is relatively short and the blast-target interaction is a transient one. Here the dynamic pressure of steady flow is not particularly pertinent, and indeed it is so ill-defined physically in these explosion situations that even its direct measurement is troublesome. Rather, for dynamic blast loads in conventional explosions the important blast-target interaction is the transient one of shock reflection.

REFLECTED OVERPRESSURES

Shock reflection effects include normal reflection, oblique reflection, and Mach stem formation. The most damaging of these, at least for tough targets, ordinarily is normal reflection. For simple air blast the overpressure developed in this reflection can be established analytically. This is conveniently described in terms of a reflection coefficient, the ratio of reflected overpressure to overpressure in the free field. For distances remote from an explosion this reflection coefficient approaches two as a lower limit, as for sound waves. It increases markedly with shock intensity, reaching about 5.8 at the nominal 16 charge radii that marks the inner limit of simple air blast in the reference explosion. Corresponding peak reflected overpressure here is 5.8 x 12 = 70 bars (100 psi) versus the 12 bars for the simple side-on overpressure. It is to be recognized that overpressures such as 70 bars can be very damaging, even though of a transient nature.

Reflection effects for composite blast close to the explosion center are more troublesome to study. Reasons for this include (1) an increase in specific heat for air and for products at the high temperatures generated in these intense shocks, (2) chemical dissociation and ionization effects, (3) nonideal gas behavior of the highly compressed gas in the intense shock, and (4) the finite time needed for an equilibrium distribution of energy within the shocked medium. An approximate analysis indicates that these complexities are unimportant at distances beyond about 10 charge radii, but that closer in they become quite marked. The approximate analysis also indicates the reflected impulse decreases monotonically with distance in contrast with the behavior of the side-on impulse. For the limiting situation on 1 charge radius, it is estimated that the reflection coefficient for normal reflection is about 12.2 (versus a theoretical maximum of 8.0 for the ideal gas with specific heat ratio 1.4). The calculated reflected overpressure at the charge surface becomes 12.2 x 450 = 5,500 bars (80,000 psi). An experimental study of these intense reflected shocks is now being planned.

BLAST LOADINGS ON STRUCTURES

In some few simple situations the load imposed by blast on a target can be calculated from fundamentals. Consider for example the blast load on the front of a disk whose surface is normal to the direction of blast-wave travel. The peak reflected transient load is the product of the peak reflected overpressure and the target area. The load decreases with time for two reasons, one the ordinary decay of the blast wave, the other a relief effect as the reflected overpressures are equalized. The decay of the blast wave has been characterized by Eq. 1. However, the reflected overpressure relief effect is an additional one superimposed on this.

With regard to the relief effect for the reflected overpressure, note that initially the reflected pressure on the face of the target is considerably greater than the pressure in the surroundings. Hence, there is flow from the face of the target into the surroundings. This relieves the reflected overpressure on the face of the target. This relief is in the form of a rarefaction wave that moves in from edge to center. Considering a particular point, the rarefaction wave arrives at some time t_1, when the pressure relief starts. This is then completed at some later time, t_2. After relief of the reflected overpressure, the disk senses only the free-field overpressure plus an incremental stagnation overpressure maintained by the impact effect of the moving blast wind.

A method of characterizing all these effects is indicated in Fig. 11 which illustrates various overpressures associated with the blast wave. The primary one of these is the side-on or free-field overpressure, but also included are the reflected and stagnation overpressures. Each varies with time, as shown. Reflected overpressure exists on the face of the disk from zero time until relief starts at time t_1, and the pressure after relief is completed at time t_2 is the stagnation overpressure. The relief process occurs between times t_1 and t_2 at intermediate pressures. Assigning representative values to times t_1 and t_2 based on speed of travel of a rarefaction wave and on dimensions of the disk, the blast load predicted for the center of a disk in a particular situation is that of Fig. 12. The general form of this predicted dynamic load on the front face can be compared with dynamic loads as measured at centers of a 3-inch disk and of a 9-inch disk and shown in Fig. 13. The general agreement between predicted and observed loads lends encouragement to this method of analysis, at least for simple targets.

DAMAGE POTENTIAL OF BLAST

Damage to a target from blast comes from motion of the target as imparted by forces of the blast wave. In principle, an analytic solution for target motion can be obtained from the equation of motion expressing the relation between target mass, its acceleration, and the unbalance between the driving force of the blast wave and the resistance of the

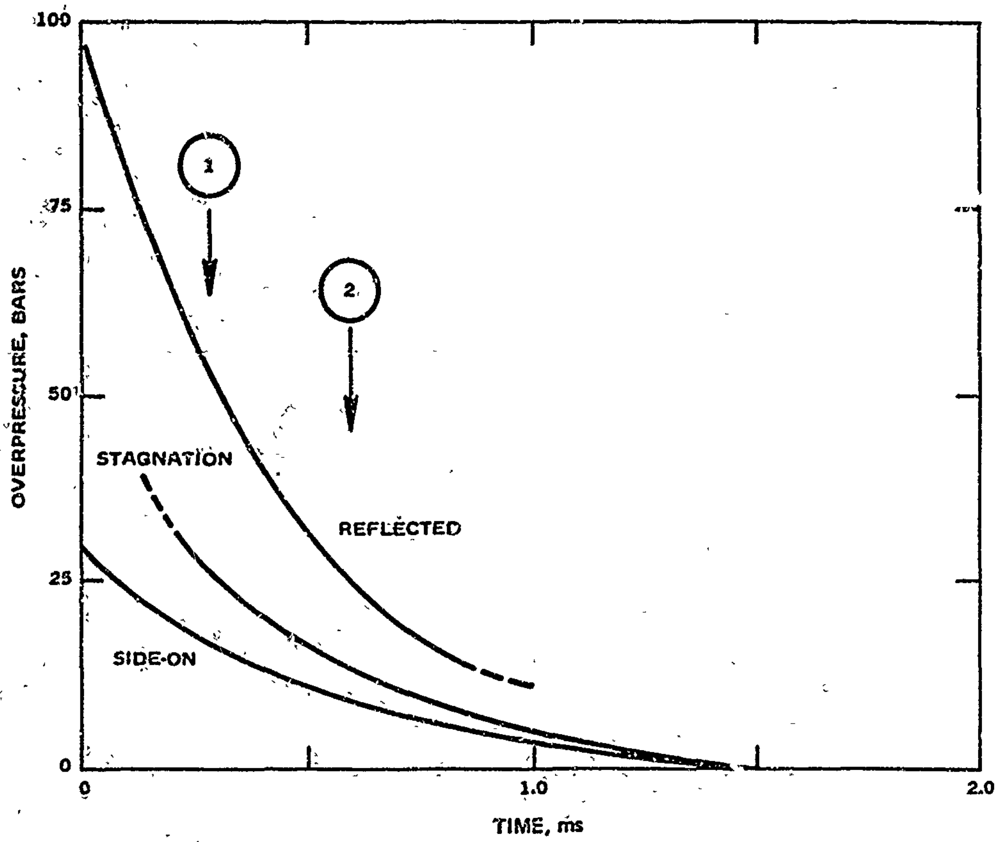


FIG. 11. Overpressure-Time Relations Needed for Determination of Dynamic Blast Load.

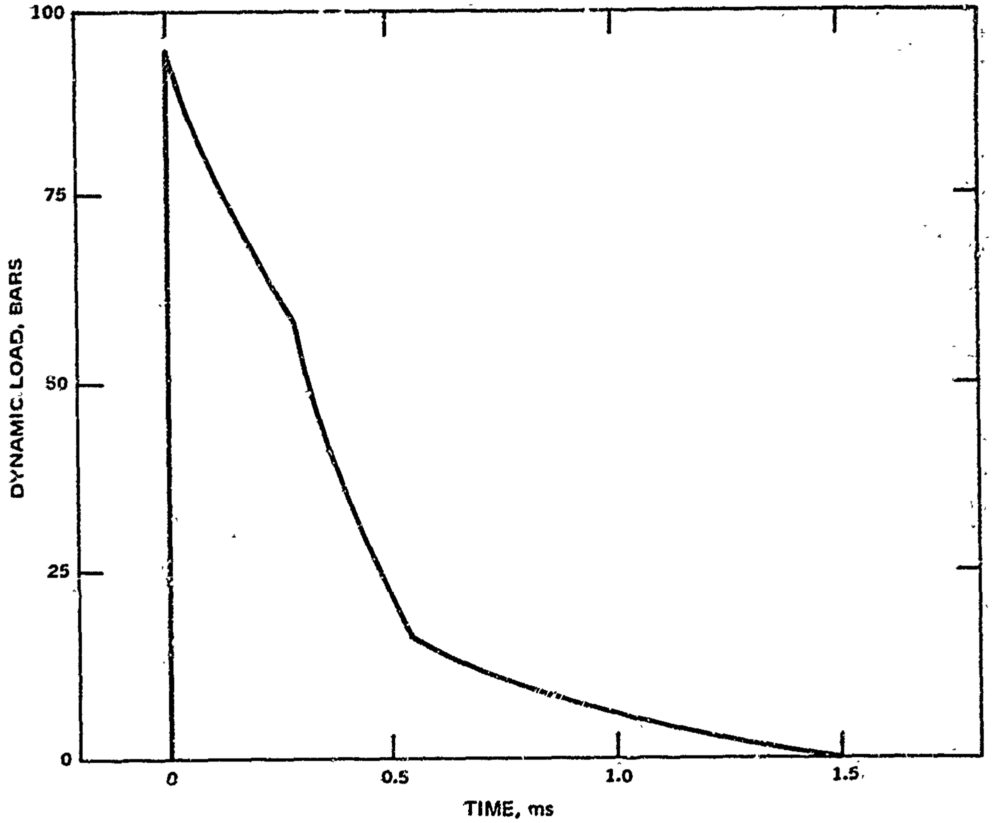
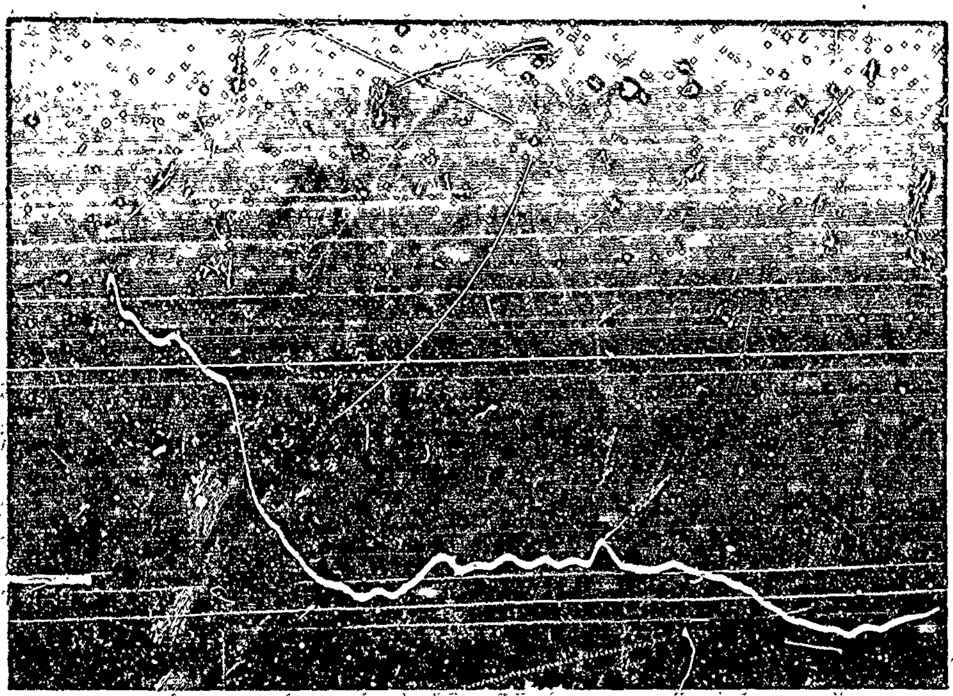


FIG. 12. Dynamic Blast Load Predicted for Center of 3-Inch Disk 5 Feet From Reference Explosion.



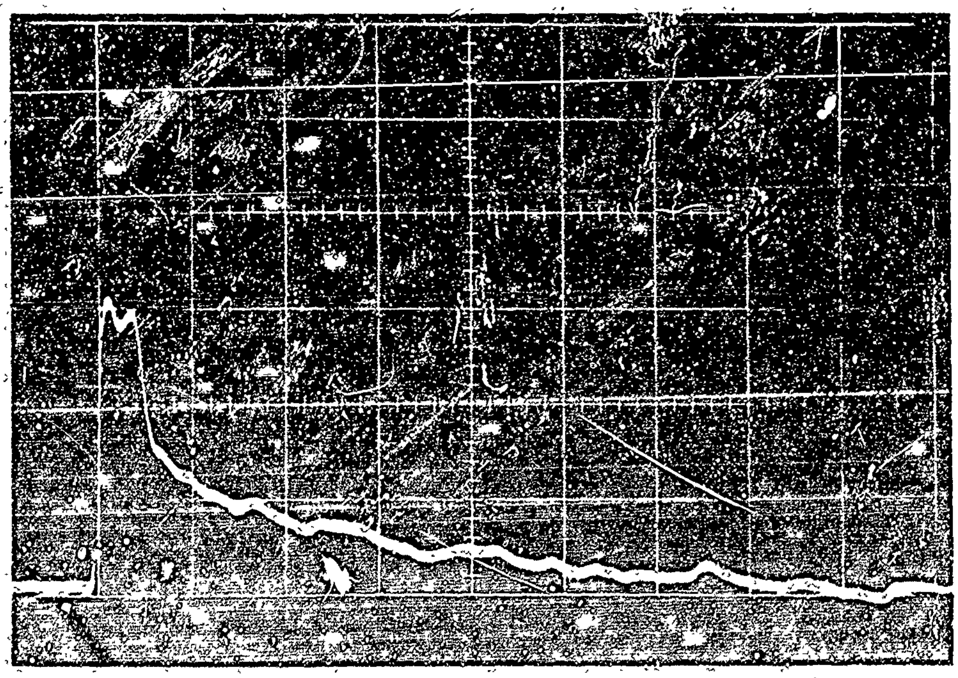


FIG. 13. Dynamic Blast Loads Measured for 9-Inch and 3-Inch Disks. (Not to same time scale.)

target. The driving force is a transient one, given as the product of target cross-section area and a blast-wave overpressure such as that of Fig. 12 or 13. The resistance of the target depends on its structural features. However, for dynamic situations this is seldom known precisely and indeed perhaps is not capable of being known. Furthermore, even if both the transient driving force of the blast wave and the dynamic resistance of the target were known, the mathematical form of the equation of motion is not conducive to a simple solution, but rather calls for numerical or analogue methods. Hence, only in simpler situations is a precise solution for target motion in response to blast to be obtained.

As an alternative to an exact solution for target motion, various empirical estimates of the damage potential of blast have been used. One of these is based on the peak overpressure in the free-field blast wave. For example, it may be stated that a peak overpressure of such and such psi causes major target damage. It should be recognized that such a statement even if correct can at best be only a crude approximation. It ignores the fact that the damage potential of blast is a function of two individual items, the transient blast loading plus the dynamic response of the target; two such aspects are always involved in assessment of damage potential.

A two-aspect criterion for blast damage potential that has met with considerable success is the "critical impulse within a critical time" (Ref. 9). This criterion states that for each possible target there exists some critical impulse above which the target is damaged if such impulse is received within a critical time, but below which there is no effect. The identification and selection of the critical time for any specific target is essentially empirical, but may logically be taken as about one-quarter the natural period of free vibration. The damage potential of the blast for some specific target becomes the net impulse per unit area obtained by time integration of the blast overpressure out only to the specified critical time. This criterion seems a realistic one, and has been shown to agree with direct observations of various damage effects in several circumstances.

An interesting point in connection with this two-aspect criterion is that the ratio of critical impulse to the critical time for any target corresponds to a sort of "critical overpressure" for that target. This critical overpressure can be interpreted as the minimum overpressure capable of causing damage, but which actually would cause damage only if sustained for at least as long as the critical time.

Appendix A

1 KILOGRAM OF TNT

BASIS ONE KILOGRAM

SCALED DISTANCE (METERS)	SHOCK FRONT MACH NUMBER	SHOCK FRONT TRAVEL TIME (MS)	SHOCK FRONT AVERAGE TRAVEL SPEED (M/MS)	SIDE-ON PEAK OVERPRESSURE (BARS)	SIDE-ON IMPULSE (BAR-MS)	SIDE-ON PRESSURE DURATION (MS)	SIDE-ON DECAY PARAMETER	REFLECTED PEAK OVERPRESSURE RATIO	REFLECTED IMPULSE (BAR-MS)	REFLECTED VELOCITY DURATION (MS)
.34	8.134	.072	4.71	76.0	1.38	.200		636.	9.8	.88
.36	7.776	.080	4.53	69.4	1.37	.182		569.	9.5	.80
.38	7.436	.087	4.36	63.3	1.36	.164		509.	9.2	.72
.40	7.116	.095	4.20	57.9	1.35	.148		457.	9.0	.65
.42	6.819	.104	4.06	53.1	1.34	.133		410.	8.9	.58
.44	6.548	.112	3.92	46.9	1.33	.120		370.	8.8	.52
.46	6.308	.121	3.80	45.2	1.32	.107		336.	8.7	.46
.48	6.083	.131	3.68	42.0	1.27	.095		308.	8.7	.42
.50	5.868	.140	3.56	39.0	1.21	.087		282.	8.6	.39
.52	5.664	.151	3.455	36.27	1.151	.082		259.	8.58	.374
.54	5.474	.161	3.354	33.80	1.065	.081		238.	8.55	.360
.56	5.299	.172	3.258	31.59	1.044	.084		220.	8.53	.353
.58	5.139	.183	3.167	29.65	.996	.092		205.	8.51	.354
.60	4.998	.195	3.081	27.97	.952	.100		191.	8.50	.361
.62	4.857	.207	2.998	26.36	.993	.132		178.	8.47	.369
.64	4.723	.219	2.920	24.86	1.043	.164		167.	8.42	.379
.66	4.596	.232	2.847	23.47	1.096	.198		156.	8.36	.392
.68	4.476	.245	2.778	22.21	1.154	.234		146.	8.30	.408
.70	4.365	.258	2.712	21.06	1.217	.272		137.	8.22	.426
.72	4.263	.272	2.650	20.03	1.283	.313		129.	8.14	.447
.74	4.170	.286	2.591	19.12	1.354	.355		122.	8.05	.470
.76	4.080	.299	2.538	18.25	1.385	.393		116.	7.92	.499
.78	3.991	.314	2.488	17.41	1.396	.427		109.	7.77	.528
.80	3.904	.328	2.439	16.62	1.402	.459		103.	7.62	.556
.82	3.821	.343	2.393	15.87	1.404	.489		98.	7.46	.583
.84	3.742	.358	2.348	15.17	1.400	.518		93.	7.30	.610
.86	3.667	.373	2.305	14.52	1.392	.545		88.	7.13	.636
.88	3.595	.389	2.263	13.91	1.378	.570		83.	6.96	.661
.90	3.528	.405	2.223	13.35	1.360	.594		79.	6.79	.685
.92	3.465	.421	2.185	12.84	1.337	.616		76.	6.61	.709

BASIS ONE KILOGRAM

	SHOCK FRONT			SIDE-ON				REFLECTED		
SCALED DISTANCE (METERS)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (M/MS)	PEAK OVERPRESSURE (BARS)	IMPULSE (BAR-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE RATIO	IMPULSE (BAR-MS)	VELOCITY DURATION (MS)
.94	3.465	.438	2.147	12.35	1.309	.634		72.	6.45	.724
.952	3.364	.448	2.124	12.04	1.292	.640	4.72	69.8	6.38	.723
.96	3.339	.455	2.110	11.64	1.282	.646	4.7	68.31	6.33	.723
.98	3.274	.473	2.074	11.34	1.257	.655	4.7	64.73	6.20	.726
1.00	3.210	.491	2.039	10.85	1.236	.666	[illegible]	61.36	6.06	.732
1.02	3.147	.509	2.004	10.39	1.217	.677	4.5	58.02	5.91	.742
1.04	3.086	.528	1.971	9.94	1.200	.687	4.4	54.88	5.75	.755
1.06	3.021	.547	1.938	9.48	1.206	.706	4.3	51.70	5.51	.797
1.08	2.957	.567	1.905	9.04	1.214	.725	4.1	48.63	5.28	.844
1.10	2.895	.587	1.874	8.61	1.224	.745	3.9	45.71	5.05	.893
1.12	2.836	.608	1.841	8.21	1.216	.758	3.8	43.04	4.92	.927
1.14	2.778	.630	1.810	7.84	1.205	.770	3.7	40.53	4.81	.957
1.16	2.723	.652	1.779	7.48	1.192	.781	3.6	38.18	[illegible]	.954
1.18	2.670	.674	1.751	7.15	1.176	.790	3.5	35.97	[illegible]	1.009
1.20	2.619	.697	1.723	6.83	1.158	.798	3.4	33.92	4.61	1.030
1.22	2.571	.718	1.698	6.54	1.140	.804	3.3	32.05	4.57	1.050
1.24	2.526	.739	1.678	6.28	1.127	.810	3.1	30.36	4.52	1.070
1.26	2.483	.760	1.658	6.02	1.114	.815	3.0	28.77	4.48	1.090
1.28	2.441	.781	1.638	5.78	1.102	.820	2.9	27.27	4.41	1.109
1.30	2.400	.803	1.619	5.56	1.090	.825	2.8	25.[illegible]	4.36	1.128
1.32	2.361	.825	1.600	5.34	1.078	.830	2.7	24.54	4.32	1.146
1.34	2.324	.848	1.581	5.13	1.066	.835	2.6	23.30	4.27	1.165
1.36	2.288	.870	1.563	4.94	1.055	.841	2.5	22.15	4.23	1.182
1.38	2.254	.894	1.544	4.76	1.044	.846	2.4	21.09	4.19	1.200
1.40	2.222	.917	1.526	4.58	1.033	.851	2.3	20.10	4.15	1.217
1.42	2.192	.941	1.509	4.44	1.022	.856	2.2	19.20	4.11	1.234
1.44	2.162	.966	1.490	4.29	1.012	.862	2.2	18.35	4.07	1.249
1.46	2.132	.995	1.468	4.14	1.003	.872	2.1	17.49	4.02	1.259
1.48	2.102	1.024	1.446	3.99	.994	.883	2.0	16.57	3.97	1.271

BASIS ONE KILOGRAM

	SHOCK FRONT			SIDE-ON				REFLECTED		
SCALED DISTANCE (METERS)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (M/MS)	PEAK OVERPRESSURE (BARS)	IMPULSE (BAR-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE RATIO	IMPULSE (BAR-MS)	VELOCITY DURATION (MS)
1.50	2.073	1.053	1.425	3.85	.985	.894	2.0	15.89	3.92	1.285
1.52	2.045	1.083	1.404	3.71	.976	.905	1.9	15.15	3.86	1.301
1.54	2.018	1.113	1.384	3.59	.967	.916	1.9	14.46	3.81	1.318
1.56	1.992	1.144	1.364	3.46	.959	.928	1.8	13.80	3.76	1.337
1.58	1.966	1.175	1.345	3.34	.951	.940	1.7	13.18	3.70	1.358
1.60	1.942	1.207	1.326	3.23	.942	.953	1.7	12.60	3.65	1.381
1.62	1.919	1.239	1.308	3.13	.934	.966	1.7	12.05	3.60	1.405
1.64	1.896	1.271	1.290	3.03	.926	.979	1.6	11.54	3.54	1.431
1.66	1.875	1.304	1.273	2.93	.919	.992	1.6	11.07	3.4[illegible]	1.459
1.68	1.855	1.338	1.256	2.85	.911	1.006	1.5	10.63	3.4[illegible]	1.489
1.70	1.836	1.372	1.239	2.76	.903	1.020	1.5	10.23	3.37	1.520
1.72	1.818	1.406	1.224	2.69	.896	1.034	1.5	9.85	3.32	1.557
1.74	1.800	1.438	1.210	2.61	.888	1.047	1.5	9.46	3.26	1.618
1.76	1.782	1.471	1.196	2.54	.880	1.060	1.4	9.13	3.21	1.679
1.78	1.765	1.505	1.183	2.47	.872	1.073	1.4	8.80	3.15	1.739
1.80	1.749	1.538	1.170	2.40	.864	1.087	1.4	8.48	3.10	1.798
1.82	1.733	1.572	1.158	2.34	.856	1.100	1.4	8.18	3.04	1.856
1.84	1.718	1.606	1.146	2.28	.848	1.113	1.3	7.90	2.99	1.914
1.86	1.703	1.640	1.134	2.22	.841	1.126	1.3	7.64	2.93	1.972
1.88	1.689	1.675	1.123	2.16	.833	1.139	1.3	7.39	2.88	2.029
1.90	1.676	1.709	1.111	2.11	.825	1.151	1.3	7.16	2.82	2.069
1.92	1.663	1.745	1.100	2.06	.817	1.163	1.3	6.93	2.77	2.080
1.94	1.650	1.781	1.089	2.01	.808	1.174	1.3	6.71	2.71	2.089
1.96	1.638	1.817	1.079	1.96	.800	1.186	1.2	6.50	2.66	2.097
1.98	1.625	1.854	1.068	1.92	.792	1.197	1.2	6.30	2.60	2.102
2.00	1.613	1.890	1.058	1.87	.784	1.209	1.2	6.10	2.55	2.106
2.05	1.584	1.983	1.034	1.761	.764	1.237	1.18	5.64	2.42	2.11
2.10	1.556	2.077	[illegible]	1.660	.745	1.265	1.14	5.23	2.29	2.10
2.15	1.531	2.172	.990	1.566	.726	1.293	1.10	4.85	2.17	2.07
2.20	1.506	2.269	.969	1.401	.708	1.321	1.06	4.51	2.06	2.04

BASIS ONE KILOGRAM

	Shock front			Side-on				Reflected		
SCALED DISTANCE (METERS)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (M/MS)	PEAK OVERPRESSURE (BARS)	IMPULSE (BAR-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE RATIO	IMPULSE (BAR-MS)	VELOCITY DURATION (MS)
2.25	1.484	2.368	.950	1.403	.690	1.348	1.03	4.21	1.95	1.99
2.30	1.464	2.468	.932	1.333	.672	1.375	1.01	3.95	1.84	1.93
2.35	1.44[illegible]	2.570	.914	1.269	.660	1.408	.99	3.71	1.78	1.95
2.40	1.427	2.674	.898	1.209	.649	1.441	.96	3.49	1.73	1.97
2.45	1.409	2.778	.882	[illegible]151	.638	1.474	.93	3.28	1.68	2.00
2.50	1.393	2.883	.867	1.097	.627	1.506	.89	3.08	1.63	2.03
2.55	1.377	2.989	.853	1.045	.617	1.538	.86	2.90	1.59	2.06
2.60	1.362	3.096	.840	.996	.607	1.571	.82	2.74	1.55	2.09
2.65	1.347	3.204	.827	.951	.598	1.602	.78	2.58	1.51	2.12
2.70	1.334	3.313	.815	.908	.589	1.634	.74	2.44	1.48	2.15
2.75	1.321	3.423	.803	.869	.580	1.666	.71	2.31	1.45	2.18
2.80	1.309	3.534	.792	.832	.572	1.697	.67	2.20	1.43	2.22
2.85	1.298	3.645	.782	.799	.564	1.728	.64	2.09	1.41	2.26
2.90	1.288	3.758	.772	.768	.557	1.758	.61	1.99	1.39	2.30
2.95	1.279	3.872	.762	.741	.550	1.789	.59	1.91	1.38	2.34
3.00	1.270	3.986	.753	.717	.544	1.819	.58	1.83	1.37	2.38
3.05	1.263	4.102	.744	.695	.538	1.849	.57	1.77	1.37	2.42
3.10	1.257	4.218	.735	.677	.532	1.879	.56	1.71	1.36	2.46
3.15	1.252	4.336	.726	.661	.527	1.909	.57	1.67	1.37	2.51
3.20	1.248	4.454	.718	.649	.522	1.938	.59	1.63	1.37	2.55
3.25	1.242	4.573	.711	.632	.516	1.965	.59	1.58	1.36	2.59
3.30	1.235	4.691	.703	.613	.508	1.990	.58	1.52	1.34	2.61
3.35	1.228	4.811	.696	.594	.500	2.014	.57	1.47	1.31	2.63
3.40	1.222	4.930	.690	.576	.492	2.037	.56	1.42	1.29	2.65
3.45	1.216	5.050	.683	.559	.484	2.059	.55	1.37	1.27	2.67
3.50	1.211	5.171	.677	.544	.477	2.080	.54	1.32	1.25	2.69
3.55	1.205	5.292	.671	.529	.469	2.101	.54	1.28	1.22	2.71
3.60	1.200	5.414	.665	.515	.461	2.120	.53	1.24	1.20	2.72
3.65	1.196	5.537	.659	.502	.453	2.139	.53	1.20	1.18	2.74
3.70	1.191	5.659	.654	.489	.445	2.157	.54	1.17	1.15	2.75

BASIS ONE KILOGRAM

SCALED DISTANCE (METERS)	SHOCK FRONT: MACH NUMBER	SHOCK FRONT: TRAVEL TIME (MS)	SHOCK FRONT: AVERAGE TRAVEL SPEED (M/MS)	SIDE-ON: PEAK OVERPRESSURE (BARS)	SIDE-ON: IMPULSE (BAR-MS)	SIDE-ON: PRESSURE DURATION (MS)	SIDE-ON: DECAY PARAMETER	REFLECTED: PEAK OVERPRESSURE RATIO	REFLECTED: IMPULSE (BAR-MS)	VELOCITY DURATION (MS)
3.75	1.187	5.783	.648	.478	.437	2.174	.55	1.14	1.13	2.76
3.80	1.183	5.907	.643	.465	.428	2.187	.55	1.10	1.11	2.77
3.85	1.178	6.032	.638	.452	.418	2.198	.55	1.07	1.08	2.78
3.90	1.173	6.157	.633	.439	.409	2.209	.54	1.03	1.06	2.79
3.95	1.169	6.282	.629	.427	.400	2.220	.54	1.00	1.03	2.80
4.00	1.164	6.407	.624	.415	.391	2.230	.53	.97	1.01	2.80
4.10	1.156	6.657	.616	.393	.375	2.249	.52	.91	.96	2.81
4.20	1.149	6.906	.608	.373	.359	2.267	.52	.86	.92	2.82
4.30	1.142	7.155	.601	.356	.346	2.284	.51	.82	.88	2.83
4.40	1.139	7.396	.595	.346	.340	2.308	.50	.79	.86	2.84
4.50	1.135	7.637	.589	.336	.335	2.332	.50	.77	.84	2.85
4.60	1.132	7.879	.584	.328	.332	2.356	.49	.75	.82	2.86
4.70	1.130	8.121	.579	.322	.329	2.380	.48	.73	.81	2.88
4.80	1.128	8.365	.574	.317	.327	2.405	.48	.72	.79	2.89
4.90	1.124	8.615	.569	.308	.322	2.429	.47	.69	.78	2.91
5.00	1.121	8.869	.564	.299	.317	2.452	.46	.67	.76	2.92
5.1	1.117	9.13	.559	.290	.311	2.47	.46	.650	.740	2.94
5.2	1.114	9.39	.554	.281	.305	2.50	.45	.628	.722	2.96
5.3	1.111	9.65	.549	.273	.298	2.52	.44	.607	.705	2.97
5.4	1.108	9.92	.544	.265	.292	2.53	.43	.587	.686	2.98
5.5	1.105	10.19	.540	.257	.286	2.54	.43	.570	.667	2.99
5.6	1.102	10.47	.535	.250	.280	2.56	.42	.553	.649	2.99
5.7	1.099	10.74	.531	.244	.274	2.57	.42	.536	.632	3.00
5.8	1.097	11.02	.526	.237	.269	2.59	.41	.521	.615	3.01
5.9	1.094	11.30	.522	.231	.264	2.60	.41	.506	.599	3.01
6.0	1.092	11.58	.518	.225	.259	2.62	.41	.492	.583	3.02
6.1	1.090	11.87	.514	.219	.254	2.63	.40	.479	.568	3.03
6.2	1.088	12.15	.510	.214	.250	2.65	.40	.466	.556	3.05
6.3	1.086	12.43	.507	.209	.247	2.68	.40	.453	.546	3.07
6.4	1.084	12.72	.503	.203	.243	2.71	.39	.441	.537	3.09

BASIS ONE KILOGRAM

SCALED DISTANCE (METERS)	SHOCK FRONT: MACH NUMBER	SHOCK FRONT: TRAVEL TIME (MS)	SHOCK FRONT: AVERAGE TRAVEL SPEED (M/MS)	SIDE-ON: PEAK OVERPRESSURE (BARS)	SIDE-ON: IMPULSE (BAR-MS)	SIDE-ON: PRESSURE DURATION (MS)	SIDE-ON: DECAY PARAMETER	REFLECTED: PEAK OVERPRESSURE RATIO	REFLECTED: IMPULSE (BAR-MS)	REFLECTED: VELOCITY DURATION (MS)
6.5	1.082	13.00	.500	.198	.240	2.74	.39	.430	.529	3.11
6.6	1.080	13.28	.497	.194	.237	2.77	.39	.419	.521	3.13
6.7	1.078	13.57	.494	.189	.234	2.80	.38	.408	.513	3.16
6.8	1.076	13.85	.491	.185	.232	2.83	.37	.398	.507	3.18
6.9	1.075	14.13	.488	.180	.229	2.86	.37	.388	.501	3.20
7.0	1.073	14.41	.486	.176	.226	2.88	.36	.379	.494	3.22
7.1	1.071	14.69	.483	.172	.222	2.89	.36	.370	.486	3.23
7.2	1.070	14.97	.481	.169	.219	2.90	.36	.361	.479	3.23
7.3	1.068	15.25	.479	.165	.215	2.92	.35	.352	.472	3.24
7.4	1.067	15.53	.477	.161	.211	2.93	.35	.344	.464	3.25
7.5	1.065	15.80	.475	.158	.208	2.94	.35	.336	.457	3.26
7.6	1.064	16.08	.473	.154	.204	2.95	.35	.329	.451	3.26
7.7	1.063	16.36	.471	.151	.200	2.96	.34	.321	.444	3.27
7.8	1.062	16.63	.469	.148	.197	2.97	.34	.314	.437	3.27
7.9	1.060	16.91	.467	.145	.193	2.97	.34	.307	.431	3.28
8.0	1.059	17.19	.466	.142	.190	2.98	.34	.301	.424	3.28
8.1	1.058	17.46	.464	.139	.187	3.00	.34	.295	.419	3.29
8.2	1.057	17.73	.462	.137	.184	3.01	.34	.289	.413	3.30
8.3	1.056	18.01	.461	.134	.182	3.02	.34	.284	.407	3.32
8.4	1.055	18.28	.460	.132	.179	3.04	.34	.276	.402	3.33
8.5	1.054	18.55	.458	.130	.177	3.05	.34	.273	.397	3.34
8.6	1.053	18.83	.457	.127	.175	3.06	.34	.268	.392	3.36
8.7	1.052	19.10	.456	.125	.173	[illegible]	.34	.263	.387	3.37
8.8	1.051	19.37	.454	.123	.170	3.09	.34	.258	.382	3.38
8.9	1.050	19.65	.453	.121	.168	3.11	.34	.254	.377	3.40
9.0	1.050	19.92	.452	.119	.166	3.12	.34	.249	.372	3.41
9.1	1.049	20.19	.451	.117	.164	3.13	.34	.245	.367	3.42
9.2	1.048	20.46	.450	.115	.162	3.15	.34	.241	.363	3.44
9.3	1.047	20.74	.448	.113	.161	3.16	.34	.237	.359	3.45
9.4	1.047	21.01	.447	.111	.159	3.18	.33	.233	.354	3.47

BASIS ONE KILOGRAM

	Shock front			Side-on				Reflected		
SCALED DISTANCE (METERS)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (M/MS)	PEAK OVERPRESSURE (BARS)	IMPULSE (BAR-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE RATIO	IMPULSE (BAR-MS)	VELOCITY DURATION (MS)
9.5	1.046	21.28	.446	.109	.157	3.19	.33	.229	.350	3.48
9.6	1.045	21.55	.445	.108	.155	3.20	.33	.226	.346	3.50
9.7	1.045	21.83	.444	.106	.154	3.22	.33	.222	.342	3.51
9.8	1.044	22.10	.443	.105	.152	3.23	.33	.219	.338	3.53
9.9	1.043	22.37	.443	.103	.151	3.25	.33	.216	.334	3.54
10.0	1.043	22.64	.442	.102	.150	3.26	.33	.213	.331	3.55
10.1	1.042	22.92	.441	.101	.148	3.27	.33	.210	.327	3.57
10.2	1.042	23.19	.440	.099	.147	3.29	.33	.207	.324	3.59
10.3	1.041	23.46	.439	.098	.146	3.30	.33	.205	.320	3.60
10.4	1.041	23.73	.438	.097	.145	3.32	.33	.203	.317	3.62
10.5	1.040	24.00	.437	.096	.144	3.33	.33	.200	.314	3.63
10.6	1.040	24.28	.437	.095	.143	3.34	.33	.197	.311	3.64
10.7	1.039	24.55	.436	.094	.141	3.35	.33	.195	.307	3.65
10.8	1.039	24.83	.435	.092	.140	3.36	.33	.192	.304	3.66
10.9	1.038	25.10	.434	.091	.139	3.38	.33	.190	.301	3.67
11.0	1.038	25.38	.433	.090	.138	3.39	.33	.187	.298	3.68
11.1	1.038	25.66	.433	.089	.137	3.40	.33	.185	.295	3.69
11.2	1.037	25.93	.432	.088	.136	3.41	.32	.183	.292	3.70
11.3	1.037	26.21	.431	.087	.134	3.42	.32	.181	.289	3.71
11.4	1.036	26.48	.431	.086	.133	3.43	.32	.179	.286	3.72
11.5	1.036	26.76	.430	.085	.132	3.44	.32	.177	.283	3.73
11.6	1.035	27.03	.429	.084	.131	3.45	.32	.175	.280	3.74
11.7	1.035	27.31	.428	.083	.130	3.46	.32	.173	.277	3.75
11.8	1.035	27.58	.428	.082	.129	3.47	.32	.171	.275	3.76
11.9	1.034	27.86	.427	.082	.129	3.48	.32	.169	.272	3.77
12.0	1.034	28.13	.427	.081	.128	3.49	.32	.167	.269	3.78
12.1	1.034	28.41	.426	.080	.127	3.50	.32	.166	.267	3.79
12.2	1.033	28.68	.425	.079	.126	3.51	.32	.164	.264	3.80
12.3	1.033	28.96	.425	.079	.125	3.52	.32	.162	.262	3.81
12.4	1.033	29.23	.424	.078	.124	3.53	.32	.161	.260	3.82

BASIS ONE KILOGRAM

	SHOCK FRONT			SIDE-ON				REFLECTED		
SCALED DISTANCE (METERS)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (M/MS)	PEAK OVERPRESSURE (BARS)	IMPULSE (BAR-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE RATIO	IMPULSE (BAR-MS)	VELOCITY DURATION (MS)
12.5	1.033	29.51	.424	.077	.123	3.54	.32	.159	.257	3.82
12.6	1.032	29.78	.423	.077	.123	3.55	.32	.158	.255	3.83
12.7	1.032	30.06	.423	.076	.122	3.56	.32	.157	.253	3.84
12.8	1.032	30.33	.422	.075	.121	3.57	.32	.155	.251	3.85
12.9	1.031	30.61	.421	.075	.121	3.58	.32	.154	.249	3.86
13.0	1.031	30.88	.421	.074	.120	3.59	.32	.153	.247	3.87
13.1	1.031	31.15	.421	.073	.119	3.59	.32	.151	.245	3.88
13.2	1.031	31.42	.420	.073	.118	3.60	.32	.150	.243	3.89
13.3	1.030	31.70	.420	.072	.118	3.61	.32	.149	.241	3.89
13.4	1.030	31.97	.419	.071	.117	3.62	.32	.147	.239	3.90
13.5	1.030	32.24	.419	.071	.116	3.63	.32	.146	.237	3.91
13.6	1.030	32.52	.418	.070	.116	3.64	.32	.145	.235	3.92
13.7	1.029	32.79	.418	.070	.115	3.65	.31	.144	.233	3.93
13.8	1.029	33.06	.417	.069	.115	3.66	.31	.142	.231	3.94
13.9	1.029	33.33	.417	.069	.114	3.67	.31	.141	.229	3.94
14.0	1.029	33.61	.417	.068	.113	3.67	.31	.140	.228	3.95
14.1	1.029	33.88	.416	.068	.113	3.68	.31	.139	.226	3.96
14.2	1.028	34.15	.416	.067	.112	3.69	.31	.138	.224	3.97
14.3	1.028	34.42	.415	.067	.112	3.70	.31	.137	.223	3.97
14.4	1.028	34.70	.415	.066	.111	3.71	.31	.136	.221	3.98
14.5	1.028	34.97	.415	.066	.110	3.71	.31	.135	.219	3.99
14.6	1.028	35.24	.414	.065	.110	3.72	.31	.134	.218	4.00
14.7	1.027	35.51	.414	.065	.109	3.73	.31	.133	.216	4.00
14.8	1.027	35.79	.414	.064	.109	3.74	.31	.132	.215	4.01
14.9	1.027	36.06	.413	.064	.108	3.74	.31	.131	.213	4.02
15.0	1.027	36.33	.413	.063	.108	3.75	.31	.139	.212	4.02
16.0	1.025	39.1	.410	.0595	.103	3.81	.31	.12	.199	4.08
17.0	1.024	41.8	.407	.0559	.098	3.85	.31	.114	.189	4.10
18.0	1.022	44.5	.404	.0525	.092	3.87	.30	.107	.180	4.12
19.0	1.021	47.3	.402	.0494	.088	3.89	.30	.101	.173	4.13

BASIS ONE KILOGRAM

SCALED DISTANCE (METERS)	SHOCK FRONT: MACH NUMBER	SHOCK FRONT: TRAVEL TIME (MS)	SHOCK FRONT: AVERAGE TRAVEL SPEED (M/MS)	SIDE-ON: PEAK OVERPRESSURE (BARS)	SIDE-ON: IMPULSE (BAR-MS)	SIDE-ON: PRESSURE DURATION (MS)	SIDE-ON: DECAY PARAMETER	REFLECTED: PEAK OVERPRESSURE RATIO	REFLECTED: IMPULSE (BAR-MS)	REFLECTED: VELOCITY DURATION (MS)
20.0	1.020	50.0	.400	.0470	.084	3.91	.30	.096	.167	4.14
21.0	1.019	52.7	.399	.0450	.081	3.93	.30	.092	.161	4.16
22.0	1.018	55.4	.397	.0430	.077	3.95	.30	.087	.156	4.18
23.0	1.017	58.1	.396	.0410	.074	3.98	.29	.083	.150	4.19
24.0	1.017	60.8	.395	.0391	.071	4.00	.29	.080	.145	4.21
25.0	1.016	63.5	.394	.0373	.068	4.01	.28	.076	.140	4.23
26.0	1.015	66.2	.393	.0355	.0656	4.03	.27	.0720	.1346	4.24
27.0	1.014	68.8	.392	.0336	.0629	4.05	.27	.0685	.1297	4.26
28.0	1.014	71.5	.391	.0321	.0603	4.07	.26	.0651	.1250	4.27
29.0	1.013	74.2	.391	.0305	.0578	4.09	.24	.0618	.1204	4.29
30.0	1.012	76.9	.390	.0289	.0553	4.11	.23	.0586	.1159	4.30
31.0	1.012	79.6	.389	.0275	.0529	4.12	.22	.0556	.1116	4.32
32.0	1.011	82.3	.389	.0260	.0507	4.14	.20	.0526	.1075	4.33
33.0	1.011	85.0	.388	.0247	.0485	4.16	.18	.0498	.1035	4.35
34.0	1.010	87.7	.388	.0233	.0464	4.17	.16	.0472	.0996	4.36
35.0	1.009	90.4	.387	.0221	.0443	4.19	.16	.0446	.0959	4.37
36.0	1.009	93.1	.387	.0209	.0424	4.20	.16	.0422	.0923	4.39
37.0	1.008	95.7	.386	.0198	.0405	4.22	.16	.0399	.0889	4.40
38.0	1.008	98.4	.386	.0187	.0388	4.23	.16	.0377	.0856	4.41
39.0	1.008	101.1	.386	.0177	.0371	4.25	.16	.0356	.0825	4.43
40.0	1.007	103.8	.385	.0167	.0355	4.26	.16	.0336	.0795	4.44
41.0	1.007	106.5	.385	.0158	.0340	4.27	.16	.0318	.0767	4.45
42.0	1.006	109.1	.385	.0150	.0326	4.28	.16	.0301	.0746	4.47
43.0	1.006	111.8	.385	.0142	.0313	4.30	.16	.0285	.0714	4.48
44.0	1.006	114.5	.384	.0134	.0301	4.31	.16	.0270	.0690	4.49
45.0	1.005	117.2	.384	.0128	.0289	4.32	.16	.0257	.0667	4.50
46.0	1.005	119.9	.384	.0122	.0279	4.33	.16	.0245	.0646	4.51
47.0	1.005	122.5	.384	.0116	.0269	4.34	.16	.0233	.0626	4.52
48.0	1.005	125.2	.383	.0111	.0260	4.35	.16	.0225	.0608	4.54
49.0	1.005	127.9	.383	.0107	.0252	4.36	.16	.0215	.0591	4.55

BASIS ONE KILOGRAM

	Shock Front			Side-On				Reflected		
SCALED DISTANCE (METERS)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (M/MS)	PEAK OVERPRESSURE (BARS)	IMPULSE (BAR-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE RATIO	IMPULSE (BAR-MS)	VELOCITY DURATION (MS)
50.0	1.004	130.6	.383	.0103	.0245	4.37	.16	.0207	.0576	4.56
51.0	1.004	133.2	.383	.0100	.0238	4.38	.16	.0201	.0562	4.57
52.0	1.004	135.9	.383	.0097	.0233	4.39	.16	.0195	.0549	4.58
53.0	1.004	138.6	.382	.0095	.0228	4.40	.16	.0191	.0538	4.59
54.0	1.004	141.2	.382	.0094	.0225	4.41	.16	.0189	.0528	4.60
55.0	1.004	143.9	.382	.0093	.0222	4.42	.16	.0187	.0520	4.61
56.0	1.004	146.6	.382	.0093	.0220	4.42	.16	.0186	.0513	4.62
57.0	1.004	149.2	.382	.0093	.0219	4.43	.16	.0187	.0508	4.63
58.0	1.004	151.9	.382	.0094	.0219	4.44	.16	.0189	.0504	4.63
59.0	1.004	154.6	.382	.0096	.0219	4.44	.16	.0192	.0502	4.64
60.0	1.004	157.2	.382	.0098	.0221	4.45	.16	.0196	.0501	4.65
61.0	1.004	159.9	.382	.0100	.0223	4.45	.16	.0202	.0501	4.66
62.0	1.004	162.5	.381	.0104	.0227	4.46	.16	.0208	.0503	4.67
63.0	1.005	165.2	.381	.0107	.0231	4.46	.16	.0216	.0507	4.68
64.0	1.005	167.9	.381	.0112	.0236	4.47	.16	.0225	.0511	4.68
65.0	1.005	170.5	.381	.0117	.0242	4.47	.16	.0235	.0518	4.69
66.0	1.005	173.2	.381	.0119	.0243	4.47	.16	.0239	.0517	4.70
67.0	1.005	175.8	.381	.0116	.0238	4.48	.16	.0233	.0507	4.70
68.0	1.005	178.5	.381	.0113	.0233	4.48	.16	.0227	.0497	4.71
69.0	1.005	181.2	.381	.0110	.0228	4.49	.16	.0221	.0487	4.71
70.0	1.005	183.8	.381	.0108	.0223	4.49	.16	.0216	.0477	4.71
71.0	1.004	186.5	.381	.0105	.0219	4.50	.16	.0211	.0468	4.72
72.0	1.004	189.2	.381	.0102	.0214	4.50	.16	.0206	.0458	4.72
73.0	1.004	191.8	.381	.0100	.0210	4.51	.16	.0201	.0449	4.73
74.0	1.004	194.5	.380	.0098	.0205	4.51	.16	.0196	.0441	4.73
75.0	1.004	197.2	.380	.0095	.0201	4.52	.16	.0191	.0432	4.73
76.0	1.004	199.8	.380	.0093	.0197	4.52	.16	.0187	.0424	4.74
77.0	1.004	202.5	.380	.0091	.0193	4.52	.16	.0183	.0416	4.74
78.0	1.004	205.2	.380	.0089	.0190	4.53	.16	.0178	.0408	4.74
79.0	1.004	207.9	.380	.0087	.0186	4.53	.16	.0174	.0401	4.74

BASIS ONE KILOGRAM

	SHOCK FRONT			SIDE-ON				REFLECTED		
SCALED DISTANCE (METERS)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (M/MS)	PEAK OVERPRESSURE (BARS)	IMPULSE (BAR-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE RATIO	IMPULSE (BAR-MS)	VELOCITY DURATION (MS)
80.0	1.004	210.5	.380	.0085	.0182	4.53	.16	.0170	.0393	4.75
81.0	1.004	213.2	.380	.0083	.0179	4.54	.16	.0167	.0386	4.75
82.0	1.003	215.9	.380	.0081	.0176	4.54	.16	.0163	.0379	4.75
83.0	1.003	218.6	.380	.0080	.0173	4.54	.16	.0160	.0373	4.76
84.0	1.003	221.3	.380	.0078	.0170	4.55	.16	.0156	.0366	4.76
85.0	1.003	224.0	.380	.0076	.0167	4.55	.16	.0153	.0360	4.76
86.0	1.003	226.6	.379	.0075	.0164	4.55	.16	.0150	.0354	4.76
87.0	1.003	229.3	.379	.0073	.0161	4.56	.16	.0147	.0349	4.76
88.0	1.003	232.0	.379	.0072	.0159	4.56	.16	.0145	.0343	4.77
89.0	1.003	234.7	.379	.0071	.0156	4.56	.16	.0142	.0338	4.77
90.0	1.003	237.4	.379	.0070	.0154	4.56	.16	.0140	.0333	4.77
91.0	1.003	240.1	.379	.0069	.0152	4.57	.16	.0138	.0328	4.77
92.0	1.003	242.8	.379	.0068	.0150	4.57	.16	.0136	.0324	4.77
93.0	1.003	245.5	.379	.0067	.0148	4.57	.16	.0134	.0320	4.77
94.0	1.003	248.2	.379	.0065	.0146	4.57	.16	.0132	.0316	4.77
95.0	1.003	250.9	.379	.0065	.0144	4.57	.16	.0130	.0312	4.78
96.0	1.003	253.6	.379	.0064	.0143	4.58	.16	.0129	.0308	4.78
97.0	1.003	256.3	.379	.0064	.0141	4.58	.16	.0127	.0305	4.78
98.0	1.003	259.0	.378	.0063	.0140	4.58	.16	.0126	.0302	4.78
99.0	1.003	261.7	.378	.0062	.0139	4.58	.16	.0125	.0299	4.78
100.0	1.003	264.4	.378	.0062	.0138	4.58	.16	.0124	.0297	4.78

Appendix B

1 POUND OF TNT

BASIS ONE POUND — 59 F, 13.6 PSIA

SCALED DISTANCE (FT)	SHOCK FRONT: MACH NUMBER	SHOCK FRONT: TRAVEL TIME (MS)	SHOCK FRONT: AVERAGE TRAVEL SPEED (FT/MS)	SIDE-ON: PEAK OVERPRESSURE (PSI)	SIDE-ON: IMPULSE (PSI-MS)	SIDE-ON: PRESSURE DURATION (MS)	DECAY PARAMETER	REFLECTED: PEAK OVERPRESSURE (PSI)	REFLECTED: IMPULSE (PSI-MS)	VELOCITY DURATION (MS)
.65	10.135	.034	19.19	1614.0	18.70	.184		14281.	139.7	.83
.70	9.633	.039	18.13	1456.3	17.38	.176		12688.	127.3	.79
.75	9.150	.044	17.21	1312.5	16.29	.167		11257.	117.0	.75
.80	8.690	.049	16.39	1182.4	15.42	.158		9983.	108.8	.71
.85	8.257	.054	15.66	1066.0	14.77	.148		8859.	102.6	.66
.90	7.856	.060	15.00	963.4	14.35	.138		7882.	98.4	.61
.95	7.492	.066	14.40	874.6	14.15	.128		7044.	96.3	.56
1.00	7.167	.072	13.87	799.2	14.08	.116		6322.	94.7	.51
1.05	6.868	.078	13.39	732.7	13.99	.104		5683.	92.9	.46
1.10	6.595	.085	12.95	674.2	13.90	.094		5129.	91.7	.41
1.15	6.349	.092	12.53	623.7	13.81	.084		4656.	90.9	.36
1.20	6.126	.099	12.14	579.6	13.43	.075		4257.	90.5	.33
1.25	5.911	.106	11.77	538.5	12.77	.068		3901.	90.1	.31
1.30	5.707	.114	11.41	500.8	12.15	.063		3582.	89.7	.29
1.35	5.515	.122	11.08	466.8	11.55	.062		3297.	89.4	.28
1.40	5.338	.130	10.76	436.2	11.02	.064		3047.	89.1	.27
1.45	5.176	.139	10.46	409.2	10.52	.069		2829.	89.0	.27
1.50	5.031	.147	10.18	385.7	10.05	.076		2643.	88.8	.28
1.55	4.892	.156	9.908	363.92	10.251	.095		2471.	88.53	.281
1.60	4.757	.166	9.651	343.25	10.752	.119		2307.	88.06	.289
1.65	4.629	.175	9.408	324.16	11.296	.145		2157.	87.51	.298
1.70	4.509	.185	9.179	306.66	11.884	.172		2020.	86.87	.309
1.75	4.396	.195	8.963	290.74	12.516	.201		1897.	86.13	.323
1.80	4.292	.206	8.758	276.40	13.191	.231		1787.	85.31	.338
1.85	4.197	.216	8.563	263.65	13.910	.263		1690.	84.40	.356
1.90	4.108	.227	8.383	251.93	14.415	.293		1601.	83.20	.376
1.95	4.019	.237	8.216	240.39	14.548	.319		1513.	81.67	.398
2.00	3.932	.248	8.057	229.47	14.631	.344		1431.	80.10	.420
2.05	3.849	.259	7.904	219.18	14.663	.368		1355.	78.49	.441
2.10	3.769	.271	7.756	209.53	14.644	.390		1283.	76.83	.461

BASIS ONE POUND 59 F; 13.6 PSIA

	SHOCK FRONT			SIDE-ON				REFLECTED		
SCALED DISTANCE (FT)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (FT/MS)	PEAK OVERPRESSURE (PSI)	IMPULSE (PSI-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE (PSI)	IMPULSE (PSI-MS)	VELOCITY DURATION (MS)
2.15	3.693	.282	7.614	200.50	14.574	.411		1216.	75.13	.481
2.20	3.620	.294	7.477	192.11	14.4[illegible]9	.431		1154.	73.38	.501
2.25	3.552	.306	7.345	184.35	14.281	.449		1098.	71.60	.519
2.30	3.488	.319	7.217	177.21	14.059	.467		1046.	69.76	.537
2.35	3.429	.331	7.094	170.71	13.786	.483		999.	67.89	.555
2.400	3.364	.344	6.973	163.74	13.496	.492	4.72	948.7	66.60	.556
2.40	3.364	.344	6.973	163.74	13.496	.492	4.7	948.72	66.60	.556
2.45	3.300	.357	6.854	156.89	13.233	.500	4.7	899.63	65.30	.556
2.50	3.236	.371	6.738	150.28	12.997	.508	4.6	852.54	63.89	.560
2.55	3.173	.385	6.625	143.90	12.788	.516	4.5	807.45	62.38	.566
2.60	3.112	.399	6.514	137.77	12.606	.524	4.5	764.35	60.77	.575
2.65	3.049	.414	6.407	131.67	12.558	.535	4.3	721.84	58.69	.597
2.70	2.986	.429	6.301	125.57	12.643	.550	4.2	679.67	56.22	.632
2.75	2.923	.444	6.197	119.69	12.739	.565	4.0	639.34	53.82	.669
2.80	2.863	.460	6.091	114.14	12.746	.578	3.9	601.71	51.98	.700
2.85	2.805	.476	5.987	108.97	12.647	.588	3.7	566.89	50.76	.724
2.90	2.749	.493	5.887	104.06	12.521	.596	3.6	534.16	49.75	.746
2.95	2.695	.509	5.791	99.40	12.370	.604	3.5	503.47	48.95	.766
3.00	2.644	.526	5.699	95.02	12.193	.610	3.4	474.80	48.35	.784
3.05	2.594	.544	5.610	90.89	11.990	.616	3.3	448.11	47.96	.799
3.10	2.549	.560	5.540	87.19	11.839	.620	3.2	424.45	47.45	.814
3.15	2.505	.575	5.475	83.70	11.706	.624	3.1	402.33	46.90	.829
3.20	2.463	.591	5.411	80.36	11.576	.628	3.0	381.45	46.37	.844
3.25	2.422	.608	5.347	77.19	11.446	.632	2.9	361.78	45.85	.858
3.30	2.382	.624	5.285	74.18	11.323	.636	2.7	343.31	45.36	.873
3.35	2.344	.641	5.223	71.34	11.201	.639	2.6	326.02	44.88	.887
3.40	2.308	.659	5.162	68.65	11.082	.643	2.5	309.88	44.43	.900
3.45	2.273	.676	5.102	66.12	10.965	.647	2.5	294.87	43.99	.914
3.50	2.240	.694	5.044	63.76	10.853	.651	2.4	280.96	43.57	.927

BASIS ONE POUND 59 F, 13.6 PSIA

SCALED DISTANCE (FT)	SHOCK FRONT MACH NUMBER	SHOCK FRONT TRAVEL TIME (MS)	SHOCK FRONT AVERAGE TRAVEL SPEED (FT/MS)	SIDE-ON PEAK OVERPRESSURE (PSI)	SIDE-ON IMPULSE (PSI-MS)	SIDE-ON PRESSURE DURATION (MS)	SIDE-ON DECAY PARAMETER	REFLECTED PEAK OVERPRESSURE (PSI)	REFLECTED IMPULSE (PSI-MS)	VELOCITY DURATION (MS)
3.55	2.209	.712	4.966	61.555	10.743	.655	2.28	268.14	43.17	.94
3.60	2.180	.730	4.929	59.513	10.635	.659	2.20	256.38	42.78	.95
3.65	2.150	.751	4.862	57.487	10.535	.665	2.13	244.84	42.32	.96
3.70	2.120	.773	4.789	55.461	10.440	.673	2.07	233.42	41.78	.97
3.75	2.091	.795	4.719	53.514	10.349	.681	2.01	222.57	41.24	.98
3.80	2.063	.817	4.650	51.646	10.253	.690	1.95	212.28	40.70	.99
3.85	2.035	.840	4.583	49.857	10.162	.698	1.89	202.53	40.15	1.00
3.90	2.009	.863	4.518	48.146	10.073	.707	1.83	193.32	39.60	1.02
3.95	1.983	.887	4.454	46.513	9.985	.716	1.78	184.63	39.05	1.03
4.00	1.958	.911	4.393	44.960	9.898	.725	1.73	176.45	38.49	1.05
4.05	1.934	.935	4.332	43.485	9.814	.735	1.68	168.78	37.93	1.07
4.10	1.911	.959	4.273	42.089	9.731	.745	1.64	161.60	37.36	1.09
4.15	1.889	.984	4.216	40.771	9.649	.755	1.60	154.89	36.79	1.11
4.20	1.869	1.010	4.160	39.532	9.569	.765	1.57	148.66	36.22	1.13
4.25	1.849	1.035	4.105	38.371	9.491	.776	1.54	142.88	35.64	1.15
4.30	1.830	1.061	4.052	37.290	9.414	.786	1.51	137.55	35.06	1.17
4.35	1.812	1.087	4.003	36.256	9.335	.797	1.49	132.51	34.48	1.21
4.40	1.795	1.112	3.958	35.237	9.252	.807	1.46	127.59	33.91	1.26
4.45	1.777	1.137	3.914	34.258	9.170	.817	1.43	122.91	33.33	1.30
4.50	1.761	1.162	3.872	33.321	9.088	.827	1.41	118.48	32.76	1.35
4.55	1.745	1.188	3.830	32.425	9.006	.837	1.38	114.28	32.19	1.39
4.60	1.729	1.214	3.790	31.571	8.924	.847	1.36	110.32	31.63	1.44
4.65	1.714	1.240	3.751	30.758	8.843	.857	1.34	106.58	31.06	1.48
4.70	1.700	1.266	3.714	29.986	8.762	.867	1.32	103.07	30.50	1.52
4.75	1.686	1.292	3.677	29.256	8.681	.877	1.31	99.78	29.93	1.57
4.80	1.673	1.319	3.640	28.559	8.597	.886	1.29	96.66	29.35	1.59
.85	1.660	1.346	3.604	27.878	8.511	.895	1.28	93.64	28.77	1.60
4.90	1.648	1.373	3.568	27.214	8.426	.904	1.26	90.73	28.19	1.61
4.95	1.635	1.401	3.534	26.566	8.341	.912	1.25	87.91	27.63	1.61
5.00	1.623	1.429	3.500	25.935	8.257	.921	1.23	85.19	27.06	1.62

BASIS ONE POUND 59 F, 13.6 PSIA

SCALED DISTANCE (FT)	SHOCK FRONT: MACH NUMBER	SHOCK FRONT: TRAVEL TIME (MS)	SHOCK FRONT: AVERAGE TRAVEL SPEED (FT/MS)	SIDE-ON: PEAK OVERPRESSURE (PSI)	SIDE-ON: IMPULSE (PSI-MS)	SIDE-ON: PRESSURE DURATION (MS)	SIDE-ON: DECAY PARAMETER	REFLECTED: PEAK OVERPRESSURE (PSI)	REFLECTED: IMPULSE (PSI-MS)	VELOCITY DURATION (MS)
5.05	1.611	1.456	3.467	25.321	8.274	.930	1.21	82.56	26.51	1.62
5.10	1.599	1.485	3.435	24.724	8.092	.938	1.20	80.03	25.97	1.62
5.15	1.588	1.513	3.404	24.143	8.011	.947	1.18	77.59	25.43	1.62
5.20	1.577	1.541	3.374	23.579	7.930	.956	1.17	75.24	24.90	1.62
5.25	1.566	1.570	3.344	23.032	7.850	.964	1.15	72.98	24.38	1.61
5.30	1.555	1.599	3.315	22.501	7.771	.973	1.13	70.81	23.87	1.61
5.35	1.545	1.628	3.287	21.987	7.692	.981	1.12	68.73	23.37	1.60
5.40	1.534	1.657	3.259	21.490	7.614	.990	1.10	66.72	22.87	1.59
5.45	1.524	1.686	3.232	21.009	7.537	.998	1.09	64.81	22.38	1.59
5.50	1.515	1.716	3.205	20.545	7.461	1.007	1.07	62.97	21.90	1.57
5.55	1.506	1.746	3.179	20.098	7.386	1.015	1.06	61.22	21.43	1.56
5.60	1.497	1.776	3.154	19.667	7.311	1.023	1.05	59.54	20.97	1.55
5.65	1.488	1.806	3.129	19.253	7.237	1.032	1.04	57.94	20.51	1.53
5.70	1.479	1.836	3.105	18.856	7.164	1.040	1.03	56.42	20.06	1.52
5.75	1.471	1.866	3.081	18.476	7.092	1.048	1.02	54.97	19.62	1.50
5.80	1.463	1.897	3.057	18.112	7.020	1.056	1.01	53.59	19.19	1.48
5.85	1.456	1.928	3.034	17.763	6.969	1.066	1.01	52.29	18.94	1.49
5.90	1.448	1.959	3.011	17.422	6.920	1.076	.99	51.01	18.70	1.49
5.95	1.441	1.991	2.989	17.087	6.871	1.086	.98	49.77	18.47	1.50
6.00	1.434	2.022	2.967	16.758	6.823	1.097	.97	48.57	18.24	1.51
6.10	1.420	2.085	2.925	16.121	6.730	1.117	.95	46.25	17.81	1.52
6.20	1.406	2.149	2.885	15.509	6.639	1.137	.92	44.05	17.40	1.54
6.30	1.393	2.213	2.847	14.922	6.551	1.156	.89	41.98	17.02	1.56
6.40	1.380	2.278	2.8[illegible]	14.362	6.466	1.176	.87	40.02	16.66	1.57
6.50	1.368	2.343	2.775	13.828	6.384	1.196	.84	38.18	16.33	1.59
6.60	1.356	2.408	2.741	13.319	6.304	1.215	.81	36.45	16.02	1.61
6.70	1.345	2.474	2.708	12.836	6.227	1.235	.78	34.82	15.73	1.63
6.80	1.334	2.540	2.677	12.379	6.153	1.254	.75	33.31	15.48	1.65
6.90	1.324	2.607	2.646	11.948	6.082	1.273	.72	31.89	15.24	1.67
7.00	1.314	2.675	2.617	11.543	6.013	1.292	.69	30.57	15.03	1.69

BASIS ONE POUND 59 F, 13.6 PSIA

	SHOCK FRONT			SIDE-ON				REFLECTED		
SCALED DISTANCE (FT)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (FT/MS)	PEAK OVERPRESSURE (PSI)	IMPULSE (PSI-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE (PSI)	IMPULSE (PSI-MS)	VELOCITY DURATION (MS)
7.1	1.305	2.74	2.589	11.163	5.948	1.31	.66	29.356	14.847	1.71
7.2	1.297	2.81	2.562	10.809	5.885	1.33	.64	28.232	14.687	1.74
7.3	1.289	2.88	2.535	10.481	5.824	1.35	.62	27.200	14.552	1.76
7.4	1.281	2.95	2.510	10.179	5.767	1.37	.60	26.258	14.442	1.79
7.5	1.274	3.02	2.485	9.903	5.712	1.39	.58	25.405	14.356	1.81
7.6	1.268	3.09	2.461	9.653	5.660	1.40	.57	24.637	14.295	1.84
7.7	1.263	3.16	2.438	9.428	5.611	1.42	.57	23.953	14.259	1.86
7.8	1.258	3.23	2.415	9.229	5.565	1.44	.56	23.352	14.247	1.89
7.9	1.253	3.30	2.393	9.056	5.521	1.46	.57	22.833	14.260	1.92
8.0	1.250	3.37	2.372	8.909	5.480	1.48	.58	22.393	14.298	1.94
8.1	1.247	3.45	2.351	8.788	5.442	1.49	.60	22.031	14.361	1.97
8.2	1.241	3.52	2.331	8.584	5.382	1.51	.59	21.429	14.206	1.99
8.3	1.236	3.59	2.312	8.372	5.317	1.53	.58	20.803	14.012	2.00
8.4	1.231	3.66	2.294	8.167	5.252	1.54	.57	20.205	13.817	2.02
8.5	1.226	3.74	2.276	7.970	5.188	1.55	.56	19.635	13.624	2.03
8.6	1.221	3.81	2.258	7.782	5.123	1.57	.56	19.092	13.431	2.04
8.7	1.216	3.88	2.241	7.602	5.058	1.58	.55	18.576	13.239	2.05
8.8	1.212	3.95	2.225	7.429	4.992	1.59	.54	18.086	13.047	2.06
8.9	1.207	4.03	2.209	7.265	4.927	1.61	.54	17.621	12.856	2.07
9.0	1.203	4.10	2.194	7.109	4.862	1.62	.54	17.182	12.666	2.08
9.1	1.199	4.18	2.179	6.961	4.797	1.63	.53	16.769	12.476	2.09
9.2	1.196	4.25	2.164	6.822	4.731	1.64	.53	16.380	12.287	2.10
9.3	1.192	4.33	2.149	6.690	4.666	1.65	.54	16.015	12.098	2.11
9.4	1.189	4.40	2.136	6.566	4.600	1.66	.54	15.675	11.910	2.12
9.5	1.186	4.48	2.122	6.448	4.533	1.67	.55	15.349	11.720	2.13
9.6	1.182	4.55	2.108	6.298	4.452	1.68	.55	14.942	11.507	2.13
9.7	1.178	4.63	2.095	6.154	4.373	1.69	.55	14.549	11.298	2.14
9.8	1.174	4.71	2.083	6.014	4.296	1.69	.54	14.171	11.094	2.14
9.9	1.171	4.78	2.070	5.878	4.221	1.70	.54	13.808	10.894	2.14
10.0	1.167	4.86	2.059	5.748	4.147	1.71	.53	13.460	10.698	2.15

BASIS ONE POUND 59 F. 13.6 PSIA

	SHOCK FRONT			SIDE-ON				REFLECTED		
SCALED DISTANCE (FT.	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (FT/MS)	PEAK OVERPRESSURE (PSI)	IMPULSE (PSI-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE (PSI)	IMPULSE (PSI-MS)	VELOCITY DURATION (MS)
10.1	1.164	4.93	2.047	5.622	4.075	1.71	.53	13.125	10.506	2.15
10.2	1.160	5.01	2.036	5.501	4.006	1.72	.53	12.805	10.320	2.16
10.3	1.157	5.09	2.025	5.385	3.938	1.73	.52	12.499	10.137	2.16
10.4	1.154	5.16	2.015	5.273	3.872	1.73	.52	12.206	9.959	2.16
10.5	1.151	5.24	2.005	5.166	3.808	1.74	.52	11.927	9.785	2.17
10.6	1.149	5.31	1.995	5.064	3.746	1.74	.52	11.661	9.615	2.17
10.7	1.146	5.39	1.985	4.966	3.686	1.75	.52	11.409	9.450	2.17
10.8	1.143	5.47	1.976	4.873	3.628	1.75	.51	11.170	9.290	2.17
10.9	1.141	5.54	1.967	4.807	3.596	1.76	.51	11.001	9.176	2.18
11.0	1.140	5.61	1.960	4.750	3.572	1.77	.51	10.855	9.078	2.18
11.1	1.138	5.69	1.952	4.696	3.549	1.77	.50	10.716	8.983	2.18
11.2	1.137	5.76	1.944	4.644	3.529	1.78	.50	10.585	8.893	2.18
11.3	1.136	5.83	1.937	4.595	3.510	1.79	.50	10.461	8.808	2.19
11.4	1.134	5.91	1.930	4.549	3.492	1.79	.49	10.344	8.726	2.19
11.5	1.133	5.98	1.923	4.506	3.477	1.80	.49	10.234	8.649	2.20
11.6	1.132	6.05	1.916	4.466	3.463	1.81	.49	10.132	8.577	2.20
11.7	1.131	6.13	1.909	4.428	3.451	1.82	.49	10.036	8.508	2.20
11.8	1.130	6.20	1.903	4.393	3.440	1.82	.48	9.948	8.444	2.21
11.9	1.129	6.28	1.896	4.361	3.431	1.83	.48	9.867	8.384	2.21
12.0	1.128	6.35	1.890	4.331	3.424	1.84	.48	9.793	8.329	2.21
12.1	1.128	6.42	1.883	4.305	3.419	1.85	.48	9.726	8.278	2.22
12.2	1.126	6.50	1.877	4.262	3.401	1.85	.48	9.621	8.211	2.22
12.3	1.125	6.58	1.870	4.214	3.378	1.86	.47	9.499	8.136	2.23
12.4	1.124	6.65	1.864	4.165	3.355	1.87	.47	9.378	8.062	2.23
12.5	1.122	6.73	1.857	4.117	3.331	1.88	.47	9.257	7.988	2.24
12.6	1.121	6.81	1.851	4.068	3.307	1.88	.46	9.137	7.915	2.24
12.7	1.120	6.89	1.844	4.020	3.283	1.89	.46	9.018	7.841	2.25
12.8	1.118	6.97	1.838	3.972	3.258	1.90	.46	8.900	7.768	2.25
12.9	1.117	7.04	1.831	3.925	3.233	1.90	.46	8.782	7.695	2.26
13.0	1.116	7.12	1.825	3.877	3.208	1.91	.45	8.665	7.622	2.26

BASIS ONE POUND

59 F, 13.6 PSIA

	SHOCK FRONT			SIDE-ON				REFLECTED		
SCALED DISTANCE (FT)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (FT/MS)	PEAK OVERPRESSURE (PSI)	IMPULSE (PSI-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE (PSI)	IMPULSE (PSI-MS)	VELOCITY DURATION (MS)
13.1	1.114	7.20	1.819	3.830	3.183	1.92	.45	8.548	7.549	2.27
13.2	1.113	7.28	1.812	3.783	3.157	1.92	.45	8.433	7.477	2.27
13.3	1.112	7.36	1.806	3.736	3.131	1.93	.44	8.318	7.404	2.28
13.4	1.110	7.44	1.800	3.689	3.104	1.94	.44	8.203	7.332	2.28
13.5	1.109	7.53	1.794	3.646	3.078	1.94	.44	8.098	7.255	2.29
13.6	1.108	7.61	1.788	3.605	3.053	1.94	.43	7.999	7.175	2.29
13.7	1.107	7.69	1.781	3.565	3.027	1.95	.43	7.902	7.097	2.29
13.8	1.106	7.77	1.775	3.525	3.002	1.95	.43	7.806	7.020	2.29
13.9	1.104	7.86	1.769	3.486	2.978	1.96	.43	7.712	6.943	2.29
14.0	1.103	7.94	1.763	3.448	2.953	1.96	.42	7.619	6.868	2.30
14.1	1.102	8.03	1.757	3.410	2.929	1.96	.42	7.528	6.793	2.30
14.2	1.101	8.11	1.751	3.373	2.906	1.97	.42	7.439	6.720	2.30
14.3	1.100	8.19	1.745	3.337	2.882	1.97	.42	7.351	6.648	2.30
14.4	1.099	8.28	1.740	3.301	2.859	1.98	.42	7.265	6.576	2.31
14.5	1.098	8.36	1.734	3.266	2.837	1.98	.41	7.181	6.506	2.31
14.6	1.097	8.45	1.728	3.231	2.814	1.99	.41	7.098	6.437	2.31
14.7	1.096	8.53	1.723	3.197	2.792	1.99	.41	7.017	6.368	2.31
14.8	1.095	8.62	1.717	3.163	2.770	1.99	.41	6.937	6.301	2.31
14.9	1.094	8.70	1.712	3.130	2.749	2.00	.41	6.859	6.235	2.32
15.0	1.093	8.79	1.707	3.098	2.728	2.00	.41	6.782	6.169	2.32
16.0	1.085	9.65	1.658	2.802	2.559	2.07	.40	6.086	5.659	2.36
17.0	1.077	10.51	1.617	2.544	2.437	2.16	.38	5.486	5.331	2.43
18.0	1.071	11.37	1.583	2.323	2.305	2.22	.36	4.977	5.047	2.48
19.0	1.065	12.22	1.555	2.127	2.154	2.26	.35	4.533	4.751	2.50
20.0	1.060	13.36	1.531	1.957	2.005	2.29	.35	4.150	4.475	2.52
21.0	1.056	13.89	1.511	1.816	1.892	2.33	.35	3.836	4.238	2.55
22.0	1.052	14.73	1.494	1.691	1.796	2.37	.34	3.560	4.023	2.59
23.0	1.049	15.56	1.478	1.581	1.711	2.41	.34	3.317	3.826	2.63
24.0	1.046	16.39	1.464	1.484	1.637	2.45	.33	3.105	3.647	2.68
25.0	1.043	17.22	1.452	1.402	1.575	2.50	.33	2.926	3.485	2.72

BASIS ONE POUND 59 F, 13.6 PSIA

	SHOCK FRONT			SIDE-ON				REFLECTED		
SCALED DISTANCE (FT)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (FT/MS)	PEAK OVERPRESSURE (PSI)	IMPULSE (PSI-MS)	PRESSURE DURATION (MS)	DECAY PARAMETER	PEAK OVERPRESSURE (PSI)	IMPULSE (PSI-MS)	VELOCITY DURATION (MS)
26.0	1.041	18.0	1.441	1.3336	1.524	2.54	.33	2.778	3.301	2.77
27.0	1.039	18.9	1.430	1.2712	1.475	2.58	.33	2.683	3.205	2.81
28.0	1.037	19.7	1.420	1.2117	1.427	2.61	.33	2.515	3.075	2.84
29.0	1.036	20.6	1.411	1.1580	1.382	2.64	.32	2.400	2.953	2.87
30.0	1.034	21.4	1.402	1.1103	1.342	2.67	.32	2.297	2.841	2.90
31.0	1.033	22.2	1.394	1.0684	1.306	2.70	.32	2.208	2.733	2.92
32.0	1.032	23.1	1.387	1.0324	1.274	2.73	.32	2.131	2.644	2.95
33.0	1.031	23.9	1.380	.9978	1.245	2.76	.32	2.050	2.557	2.98
34.0	1.030	24.7	1.374	.9653	1.217	2.79	.32	1.989	2.475	3.00
35.0	1.029	25.6	1.369	.9350	1.191	2.81	.31	1.925	2.399	3.03
36.0	1.028	26.4	1.364	.9069	1.166	2.84	.31	1.865	2.328	3.05
37.0	1.027	27.2	1.359	.8811	1.143	2.86	.31	1.811	2.262	3.07
38.0	1.027	28.1	1.354	.8574	1.121	2.88	.31	1.761	2.202	3.09
39.0	1.026	28.9	1.350	.8359	1.100	2.90	.31	1.715	2.147	3.11
40.0	1.025	29.7	1.346	.8166	1.081	2.92	.31	1.675	2.098	3.13
41.0	1.025	30.6	1.342	.7961	1.059	2.94	.31	1.632	2.053	3.14
42.0	1.024	31.4	1.338	.7762	1.037	2.95	.31	1.590	2.011	3.15
43.0	1.024	32.2	1.335	.7570	1.016	2.96	.31	1.550	1.971	3.15
44.0	1.023	33.1	1.331	.7383	.994	2.97	.30	1.511	1.933	3.16
45.0	1.022	33.9	1.328	.7204	.973	2.97	.30	1.473	1.898	3.16
46.0	1.022	34.7	1.325	.7030	.953	2.98	.30	1.437	1.864	3.17
47.0	1.021	35.5	1.322	.6863	.932	2.99	.30	1.402	1.833	3.17
48.0	1.021	36.4	1.319	.6703	.912	2.99	.30	1.369	1.804	3.17
49.0	1.020	37.2	1.317	.6560	.894	3.00	.30	1.339	1.777	3.18
50.0	1.020	38.0	1.315	.6446	.881	3.00	.30	1.315	1.753	3.18
60.0	1.017	46.3	1.297	.5369	.751	3.07	.29	1.092	1.523	3.23
70.0	1.014	54.5	1.285	.4417	.636	3.12	.26	.896	1.31[illegible]	3.28
80.0	1.011	62.7	1.277	.3591	.535	3.18	.21	.726	1.134	3.32
90.0	1.009	70.9	1.270	.2889	.449	3.22	.16	.583	.975	3.37
100.0	1.007	79.0	1.265	.2314	.377	3.27	.16	.486	.841	3.41

BASIS ONE POUND 59 F, 13.6 PSIA

SCALED DISTANCE (FT)	MACH NUMBER	TRAVEL TIME (MS)	AVERAGE TRAVEL SPEED (FT/MS)	SIDE-ON PEAK OVERPRESSURE (PSI)	SIDE-ON IMPULSE (PSI-MS)	SIDE-ON PRESSURE DURATION (MS)	DECAY PARAMETER	REFLECTED PEAK OVERPRESSURE (PSI)	REFLECTED IMPULSE (PSI-MS)	VELOCITY DURATION (MS)
SHOCK FRONT				SIDE-ON				REFLECTED		
110.0	1.006	87.2	1.261	.1863	.3186	3.31	.16	.3748	.7295	3.44
120.0	1.005	95.4	1.259	.1538	.2749	3.34	.16	.3091	.6423	3.48
130.0	1.004	103.5	1.256	.1338	.2456	3.37	.16	.2687	.5788	3.51
140.0	1.004	111.6	1.254	.1263	.2305	3.39	.16	.2536	.5392	3.54
150.0	1.004	119.7	1.253	.1314	.2298	3.41	.16	.2638	.5233	3.57
160.0	1.005	127.9	1.251	.1490	.2433	3.43	.16	.2993	.5313	3.59
170.0	1.005	136.0	1.250	.1558	.2461	3.44	.25	.3131	.5245	3.61
180.0	1.004	144.1	1.249	.1413	.2263	3.46	.25	.2839	.4843	3.62
190.0	1.004	152.2	1.248	.1284	.2086	3.47	.23	.2579	.4481	3.64
200.0	1.004	160.4	1.247	.1172	.1929	3.48	.20	.2352	.4157	3.64

Appendix C

ILLUSTRATIVE CALCULATIONS

The scaling laws in their simplest form are adequate for the following calculations.

A. A spherical charge equivalent to 27 pounds of TNT explodes in the ordinary atmosphere. At what distance should a gage be placed for peak side-on overpressures in the order of 50 psi?

Answer: The scaled distance for a peak side-on overpressure of 50 psi is found in Appendix B to be about 3.85 feet. Actual distance by Eq. 10 = $3.85 \times (27)^{1/3} = 11.5$ feet.

B. What is the duration for the positive side-on overpressure for the blast wave of calculation A?

Answer: From Appendix B, the scaled side-on duration is obtained as 0.698 ms. Actual duration by Eq. 11 = $0.698 \times (27)^{1/3} = 2.1$ ms.

C. What positive impulse is anticipated for the gage of calculation A?

Answer: Appendix B lists scaled side-on impulse as 10.16 psi-ms. Actual impulse by Eq. 12 = $10.16 \times (27)^{1/3} = 30.5$ psi-ms.

D. Write an analytic expression for the overpressure time curve for the gage of calculation A.

Answer: From Appendix B, decay parameter b is found as 1.9 (closely) and the duration has been established as 2.1 ms. Hence the term b/t_d of the exponent for the decay relation of Eq. 1 becomes $1.9/2.1 = 0.9$. Substituting

$$\text{overpressure} = 50(1 - t/2.1)e^{-0.9t}$$

where t is the time (in milliseconds) after the blast wave strikes the gage.

E. What peak overpressure would be felt by a gage at the same distance of 11.5 feet, but 1, that is part of an unyielding surface face-on to the blast wave of calculation A? Compare with the side-on value.

Answer: At the specified scaled distance of 3.85 feet, the peak reflected overpressure is given directly in Appendix B to be about 205 psi. This compares with the side-on value of 50 psi and corresponds to a reflection coefficient of 4.1.

F. A peak side-on overpressure of 59.5 psi is recorded as a distance of 10 feet from an explosion. What is the indicated equivalent yield, in pounds of TNT?

Answer: This peak side-on overpressure corresponds by Appendix B to a scaled distance of 3.60 feet. Then, by the yield equation, Eq. 14,

$$\text{equivalent yield} = \left(\frac{\text{actual distance}}{\text{scaled distance}}\right)^3 = (10/3.6)^3 = 21 \text{ pounds TNT}$$

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13. ABSTRACT

Two rather distinct types of blast are generated in the ordinary atmosphere in a conventional explosion. One is a close-in composite blast that involves both explosion products and air; the other is a more remote blast that involves atmospheric air only. These two types of blast are described qualitatively and quantitatively in terms of a reference explosion, chosen here as that of a bare spherical charge of unit mass of TNT in the ordinary atmosphere. The scaling laws for explosions which are geometrically similar are deduced from basic principles, and their limitations carefully outlined. Representative applications are illustrated by numerical examples. The transient nature of blast is one of its important aspects and makes it difficult to establish its damage potential by analytic means in any except the simplest circumstances. Hence, there is still need for semi-empirical methods such as one based on critical impulse delivered within a critical time. Detailed tables for characteristics of blast from reference explosions (Appendixes A and B) give values for peak overpressure, impulse, decay characteristics, and travel and duration times, all as a function of distance and for both free-field and normal reflection situations. ( )

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Reference explosicns						
Composite blast; explosion products and air						
Air blast						
Spherical charge of TNT						

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