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TECHNICAL REPORT ARBRL-TR-02555

AIRBLAST PARAMETERS FROM TNT SPHERICAL AIR BURST AND HEMISPHERICAL SURFACE BURST

Charles N. Kingery

Gerald Bulmash

April 1984

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report ARBRL-TR-02555	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AIRBLAST PARAMETERS FROM TNT SPHERICAL AIR BURST AND HEMISPHERICAL SURFACE BURST		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Charles N. Kingery Gerald Bulmash		8. CONTRACT OR GRANT NUMBER(s) CE-BRL-82-1
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Ballistic Research Laboratory, ARDC ATTN: DRSMC-BLT(A) Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US ARMY AMCCOM, ARDC Ballistic Research Laboratory, ATTN: DRSMC-BLA-S(A) Aberdeen Proving Ground, MD 21005		12. REPORT DATE April 1984
		13. NUMBER OF PAGES 62
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to US Government agencies only; Export Limitations; April 1984. Other requests for this document must be referred to Director, US Army Ballistic Research Laboratory, ARDC, ATTN: DRSMC-BLA-S(A), Aberdeen PROVING Ground, MD 21005.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work was performed for and funded by the Department of Defense Explosives Safety Board, 2461 Eisenhower Avenue, Alexandria, VA 22331.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

TNT Explosive
Pentolite Explosive
Airblast Parameters
Scaling
Spherical Charges
Hemispherical Charges
Free-Air Bursts
Blast Parameters

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents a compilation of data on airblast parameters from TNT spherical air bursts and hemispherical surface bursts. Functional equations have been derived, tabulations are listed, and curves of blast parameters versus scaled distances are presented in both Metric units and English units.

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I. INTRODUCTION

A. Background

A tri-service technical manual[1] published in 1969 included, among other things, airblast parameters associated with the detonation of a TNT sphere in free-air and a TNT hemisphere on the surface. This manual is being revised and updated to include new data relating blast phenomenology, and structural loading and response.

B. Objectives

The objectives of this report are to compile, analyze, and present in a usable form the various airblast parameters associated with TNT spherical free-air bursts and hemispherical surface bursts. The data will be scaled to one kilogram mass as well as one pound mass at standard sea level atmospheric conditions. To facilitate utilization, the parameters have been processed through a curve-fitting technique and are represented by polynomial functions. The equations and curves related to spherical TNT free-air bursts are presented in Appendix A while those related to hemispherical TNT surface bursts are presented in Appendix B. Presentations are made in both Metric and English units.

II. PROCEDURE

Data from many different sources were used in compiling the results presented in this report. Charge masses less then 1 kg to over 400,000 kg have been detonated and the resulting data are included in the analysis in the following sections. The description of the following blast parameters are common to spherical free-air bursts and the hemispherical surface bursts.

A. Scaling Procedure

All blast parameters were scaled to standard atmospheric sea level conditions for a one kilogram mass of explosive and a one pound mass of explosive using Hopkinson and Sachs Scaling laws.[2,3] According to Hopkinson Scaling, if R_1 is the distance from a reference explosion of Q_1

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[1] *Department of the Army, the Navy, and the Air Force, "Structures to Resist the Effects of Accidental Explosions," TM 5-1300, June 1969.*

[2] *C.N. Kingery, "Air Blast Parameters versus Distance for Hemispherical TNT Surface Bursts," BRL Report No. 1344, September 1966 (UNCLASSIFIED) AD 811673.*

[3] *Wilfred E. Baker, Explosions in Air, 1973, University of Texas Press, Austin, Texas, pp. 54-57.*

kilograms at which a specific blast pressure occurs, then for any explosion of Q_2 kilograms the same pressure will occur at a distance R_2 given by:

$$\frac{R_2}{R_1} = \left(\frac{Q_2}{Q_1}\right)^{1/3} . \qquad (1)$$

Applying these same relationships to time and impulse gives the following relationships:

$$\frac{t_2}{t_1} = \frac{R_2}{R_1} = \left(\frac{Q_2}{Q_1}\right)^{1/3} , \qquad (2)$$

and

$$\frac{I_2}{I_1} = \frac{R_2}{R_1} = \left(\frac{Q_2}{Q_1}\right)^{1/3} . \qquad (3)$$

Sachs Scaling must be applied to account for differences in atmospheric conditions. Therefore, to use the curves or tabulations in this report for predicting the blast parameters for other atmospheric conditions and charge masses the following scaling factors should be used. That is, multiply the values presented in this report by the scaling factors obtained from the following equations:

$S_p = (p_a/p_o)$ Pressure scaling factor, (4)

$S_d = (Q_2)^{1/3}\ (p_o/p_a)^{1/3}$ Distance scaling factor, (5)

$S_t = (Q_2)^{1/3}\ (p_a/p_o)^{1/3}\left(\frac{T_o}{T_a+273}\right)^{1/2}$ Time scaling factor, and (6)

$S_i = (Q_2)^{1/3}\ (p_o/p_a)^{2/3}\left(\frac{T_o}{T_a+273}\right)^{1/2}$ Impulse scaling factor. (7)

The symbols and abbreviations used in this report are defined as follows:

C_o = Sound Velocity at sea level 331 m/sec or 1086 ft/sec,

I_1 = Impulse for 1 kg or 1 lbm, kPa-ms or psi-msec,

I_2 = Impulse for other charge masses,

M = Shock front Mach number, U/C_o,

p_a = ambient atmospheric pressure,

p_o = Standard sea level atmospheric pressure 101.3 kPa, 14.69 psi,

P = peak overpressure at ambient conditions,

P_s = peak overpressure, standard sea level conditions,

Q_1 = explosive mass 1 kg,

Q_2 = other explosive masses in kg,

R_1 = distance from point of detonation of Q_1,

R_2 = distance from point of detonation for Q_2,

t_{a1} = time of arrival of shock from Q_1, msec,

t_{a2} = time of arrival of shock from Q_2, msec,

t_{+1} = duration of positive overpressure from Q_1, msec,

t_{+2} = duration of positive overpressure from Q_2, msec,

T_a = ambient temperature, degrees centigrade,

T_o = standard temperature, 288^o Kelvin,

U = velocity of shock front, m/sec or ft/sec, and

W = explosive mass in pounds.*

The incident blast parameters for one kilogram of explosive (Q_1) are shown graphically in Figure 1.

B. Shock Wave Arrival Time

The arrival time of the shock wave at a specific distance from an explosive source is one of the primary blast parameters. It is the interval of time between the initiation of the detonator and the arrival of the shock wave at a target or gage location. The arrival time includes the time for the detonation wave to propagate through the charge. It can be measured by several methods. These methods will be mentioned only briefly.

One method is the use of high speed photography to record the passage of the shock wave across a patterned backdrop. High speed photography can also be used to record the deflection of smoke trails from rockets fired just prior to detonation of the charge as well as smoke puffs in a fixed pattern just prior to detonation.

A second method which is a more direct measurement is the use of blast switches located at fixed distances from the explosive source. When the blast wave strikes each switch an electrical signal is transmitted over cable and recorded as a function of time. Overpressure transducers also record the arrival time of the shock wave, and this technique is a variation of the blast switch method.

W may be substituted for Q in Equations 1, 2, 3, 5, 6, and 7

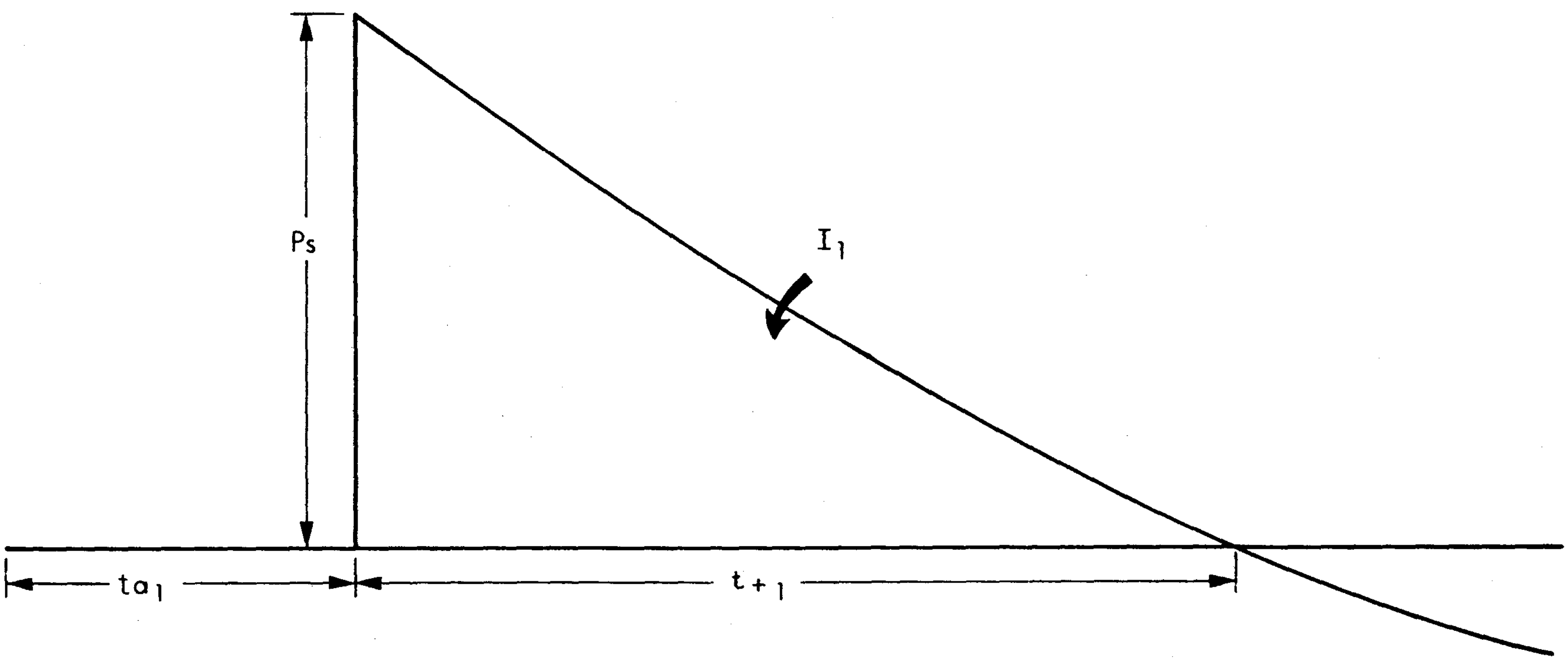

Figure 1. Incident Blast Parameters Presented in this Report.

In order to bring all measured arrival time data to a common baseline for input to the computer program the measured arrival times were scaled by the reciprocal of Equation (6) and the measured distance was scaled by the reciprocal of Equation (5) for both Q_1 in kilogram and W_1 in pounds mass.

The measurement of arrival time of the shock wave at specific gage stations is one of the more direct measurements and there is less data scatter in the reported results than found in any of the other blast parameters. Data were taken from References 1, 2, 3, 4, 5, 6, 7, 8, and 9.

C. Peak Overpressure

Peak overpressure is one of the primary blast parameters used to relate structural damage to an explosive source. The peak overpressure at the shock front may be measured directly from pressure-sensitive transducers or it may be inferred from the velocity of the shock front. This relationship will be discussed later. The data used to develop the peak overpressure versus distance curves presented in this report were compiled from many sources.[1-9] Both the data for a TNT sphere detonated in free-air and a TNT hemisphere detonated on the surface will be presented in Metric and English units. The measured values of peak overpressure were scaled to sea level atmospheric conditions using the reciprocal of Equation (4), while the distances were scaled using the reciprocal of Equation (5).

D. Overpressure Impulse

The incident overpressure impulse is the integrated area under the pressure versus time record as shown in Figure 1. It is a function of the overpressure, the duration of the blast wave, and the rate of decay of

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[4] *H.J. Goodman, "Compiled Free-Air Blast Data on Bare Spherical Pentolite," BRL Report No. 1092, February 1960 (AD 235278).*

[5] *US Department of Energy, "A Manual for Prediction of Blast and Fragment Loadings on Structures," November 1980, DOE/TIC-11268.*

[6] *R. Reisler, B. Pettit, and L. Kennedy, "Air Blast Data from Height-of-Burst Studies in Canada, Vol. I: HOB 5.4 to 71.9 feet," BRL Report No. 1950, December 1976 (AD B016344L).*

[7] *R. Reisler, B. Pettit, and L. Kennedy, "Air Blast Data from Height-of-Burst Studies in Canada, Vol. II, HOB 45.4 to 144.5 Feet," BRL Report No. 1990, May 1977.*

[8] *M. Swisdak, Jr., "Explosion Effects and Properties, Part I Explosion Effects in Air," NSWC/WOL/TR 75-116, October 1975.*

[9] *Nuclear Weapons Blast Phenomena, Volume IV, "Simulation of Nuclear Airblast Phenomena with High Explosives (U)," DASA 1200-IV, July 1973 (SECRET FRD).*

pressure behind the shock front. All values of impulse were scaled to standard sea level conditions for a 1 kg charge using the reciprocal of Equation (7). The measured distances were scaled by the reciprocal of Equation (5). The data are also scaled for a charge of one pound mass.

E. Positive Duration

The positive duration of the blast wave designated as t_{+1} in Figure 1 is one of the more difficult blast parameters to measure with consistency and repeatability. The problem is to determine the point at which the overpressure decays to ambient pressure and starts negative or when the gage starts to record an underpressure. Data from the various sources were scaled to standard sea level conditions and 1 kilogram using reciprocals of Equations (5) and (6) to bring the results to a common baseline for comparison.

F. Shock Velocity

The velocity of the shock wave is not a direct measurement but is determined from the arrival time versus distance measurements.

$$U = \frac{dR_1}{dt_{a1}} \tag{8}$$

One reason for measuring the arrival time of the shock wave at selected distances from the detonation is to determine the velocity of the shock front. From this information it is then possible to derive the peak overpressure from the Rankine-Hugoniot relationship.[10]

$$\frac{P_s}{P_o} = \left(\left(\frac{U}{C_o}\right)^2 - 1\right) \cdot \left(\frac{2\gamma}{\gamma+1}\right) \tag{9}$$

where, C_o = velocity of sound, 0^oC

U = shock velocity,

γ = variable ratio of specific heats.

G. Reflected Overpressure

The reflected peak overpressure is an important blast parameter when predicting the blast loading and relating structural damage to buildings. Reflected overpressure is usually not a direct measurement except for tests conducted to determine the effects of charge height of burst on blast measurements made along the ground. The only reflected overpressure data presented in this report are those normal to the surface or the head-on reflections. Data recorded at stations directly below the charges from References 6 and 7 were used in establishing the tables and curves in this report. There is also a relationship between the incident peak overpressure

[10] *R.E. Shear and B.D. Day, "Tables of Thermodynamic and Shock Front Parameters for Air," BRL M-1206, May 1959, AD 219224.*

P_s and the reflected pressure P_r. The reflected pressure can be calculated from the following equation.

$$P_r = P_1 \frac{(2 + \frac{1}{\mu^2})(\frac{P_1}{P_o}) - 1}{\frac{1}{\mu^2} + \frac{P_1}{P_o}} - P_o \qquad (10)$$

where $P_1 = P_s + p_o$

$$\frac{1}{\mu^2} = \frac{\gamma + 1}{\gamma - 1}$$

γ = variable ratio of specific heat

The ratio of specific heat (γ) is a function of peak overpressure. This relationship is presented in Reference 11 in both tabular and graphic form.

H. Reflected Impulse

Reflected impulse (I_r) is a primary blast damage mechanism, yet there is a lack of specific measurements of this blast parameter. Unlike reflected pressure there is not a simple calculational technique which allows you to relate reflected impulse to incident impulse. The reflected impulse curve for free-air presented in Reference 1 was modified based on data from References 4, 6, and 7. Data from Reference 4, which presents reflected impulse for spherical Pentolite, was scaled to TNT using a TNT equivalency of 1.17 and used in constructing the curve.

There was no data presented in Reference 2 on reflected impulse; therefore, the free-air spherical TNT curve was scaled to hemispherical TNT reflected impulse versus distance curve by assuming a reflection factor of 1.8 Q or W.

III. PRESENTATION OF DATA

The data presentation and analysis will be made in two divisions. The first division will include the spherical TNT free-air blast parameters presented in graphic form in English units. The reason for the presentation in English units is that all source material was in English units which allowed direct comparisons with the curves developed from the polynomial equations. The second division will discuss the hemispherical TNT surface burst blast parameters.

A. Functional Presentation

The blast parameters are represented by polynomial functions that were generated interactively with a Tektronix 4051 microcomputer system possessing graphics capability. The X, Y data arrays were input to a logarithm plotting program* which was interfaced with a Tektronix statistical software package.[12] Because the parameters range over several logarithm cycles, the arrays were converted to logarithmic form and reformatted for input to the statistical package where trial functions were generated. Equations were appended to the logarithm plotting program, then data and functions were graphed concurrently to test the accurateness of fit.

The Tektronix polynomial regression program performs a least-squares polynomial fit through the X, Y data generating a smooth line using Equation (11).

$$Y = C_o + C_1 U + \ldots\ldots + C_N U^N, \tag{11}$$

where $U = K_o + K_1 T$; and

C and K are calculated constants;

T is the common logarithm of the distance,
Y is the common logarithm of the parameter under evaluation, and
N is the degree of fit.

The BRL Cyber 173 mainframe computer was utilized, using Disspla software,[13] to generate graphs and tabular listings, with variable increments,** from the statistically derived functions. The functional equations are presented in Appendices A and B.

B. Spherical TNT Free-Air Burst

The airblast parameters versus distance presented in this report are compiled from many sources.[1-11] In order to fill in certain gaps in the available TNT data, results from spherical Pentolite detonated in free-air and hemispherical TNT surface bursts were used with appropriate scaling.

1. Peak Overpressure. The peak overpressure versus scaled distance tabulations presented in this report were developed from data reported in References 1-10. Rather than research the sources used in many reports

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* *Logarithm plotting program by Rodney Abrahams, BRL, September 1981.*

** *T.A. Zaker, Department of Defense Explosive Safety Board, May 1982, private communication.*

11 *C.N. Kingery and B.F. Pannill, "Parametric Analysis of the Regular Reflection of Air Blast," BRL Report 1249, June 1964 (AD 444997).*

12 *Tektronix Manual, "Tektronix Plot 50 Mathematics Volume 2," December 1975.*

13 *Integrated Software Systems Corporation, "Disspla Version, 8.2," Copyrighted 1975.*

such as Reference 8 which was based on nine sources, and Reference 9 which had even more sources, the tables presented in these basic reports were used as data points for establishing the polynomial equations which describe the peak overpressure versus scaled distance. New data based on recent spherical free-air TNT tests reported in References 6 and 7 were used over a range of 1588 kPa down to 11 kPa. Data from Reference 8 covers a range of peak overpressures from 5500 kPa down to 3.4 kPa while Reference 9 covers a range from 47570 kPa down to 0.28 kPa. It is generally accepted that peak overpressure can be measured to accuracies of $\pm$ 10 percent. This error band includes atmospheric conditions that may not be accounted for, errors in explosive yield, errors in gage response, errors in range measurements, and gage calibration errors.

The peak overpressures scaled to standard sea level conditions versus scaled distances for a spherical TNT free-air burst are listed in Table 1 in Metric units and in Table 2 in English units. In Figure 2 the solid line is the peak overpressure versus distance generated from the equation developed by the polynomial fitting technique. Also presented in Figure 2 are the data from the major input sources to show a comparison and accurateness of fit. Figure 2 is plotted in English units because the source data are in English units. Polynomial equations for both Metric and English units are presented in Appendix A. Plots of the blast parameters versus scaled distance in Metric units and English units are also presented in Appendix A.

2. <u>Shock Front Velocity.</u> The arrival time of the shock wave at selected distances from an explosion is a measure of the velocity of the shock wave, and using the Rankine-Hugoniot relationship the peak overpressure at the shock front can be calculated. Conversely if the peak overpressure at the shock front is known then the velocity of the shock front can be obtained from shock front parameter tables presented in Reference 10. The shock front velocity (U) can also be calculated from equation (12).

$$U = C_o\left(1 + \frac{\gamma+1}{2\gamma}\right) \cdot \frac{P_s}{P_o}^{1/2}, \tag{12}$$

where C_o = velocity of sound 331 m/sec or 1086 ft/sec,

γ = 1.402 to 1.176 variable with overpressure (see table in Reference 11),

P_s = Peak overpressure kPa or psi, and

P_o = atmospheric pressure at sea level 101.3 kPa or 14.69 psi.

The shock front velocities were calculated from Equation (12) and are listed in Tables 1 and 2. The values are not plotted on a separate graph to show comparisons with other sources or data but are presented in Appendix A with other blast parameters. The polynomial equation describing the shock front velocity versus distance is also presented in Appendix A.

TABLE 1. AIRBLAST PARAMETERS VERSUS DISTANCE FOR A ONE KILOGRAM TNT SPHERICAL AIR BURST

DISTANCE (M)	INCIDENT PRESSURE (kPa)	INCIDENT IMPULSE (kPa-msec)	REFLECTED PRESSURE (kPa)	REFLECTED IMPULSE (kPa-msec)	SHOCK VELOCITY (M/msec)	ARRIVAL TIME (msec)	POSITIVE PHASE DURATION (msec)
5.31×10^{-2}	4.89×10^{4}	2.60×10^{3}	6.22×10^{5}	8.04×10^{4}	6.63×10^{0}	7.71×10^{-3}	
6.00×10^{-2}	4.56×10^{4}	2.13×10^{3}	5.66×10^{5}	6.18×10^{4}	6.39×10^{0}	8.69×10^{-3}	
7.00×10^{-2}	4.11×10^{4}	1.60×10^{3}	5.04×10^{5}	4.47×10^{4}	6.07×10^{0}	1.03×10^{-2}	
8.00×10^{-2}	3.71×10^{4}	1.23×10^{3}	4.53×10^{5}	3.40×10^{4}	5.78×10^{0}	1.20×10^{-2}	
9.00×10^{-2}	3.37×10^{4}	9.63×10^{2}	4.08×10^{5}	2.68×10^{4}	5.52×10^{0}	1.38×10^{-2}	
1.00×10^{-1}	3.08×10^{4}	7.75×10^{2}	3.68×10^{5}	2.18×10^{4}	5.29×10^{0}	1.57×10^{-2}	
1.20×10^{-1}	2.61×10^{4}	5.37×10^{2}	3.03×10^{5}	1.54×10^{4}	4.89×10^{0}	1.97×10^{-2}	
1.40×10^{-1}	2.25×10^{4}	4.01×10^{2}	2.53×10^{5}	1.16×10^{4}	4.54×10^{0}	2.40×10^{-2}	
1.60×10^{-1}	1.96×10^{4}	3.17×10^{2}	2.14×10^{5}	9.12×10^{3}	4.24×10^{0}	2.85×10^{-2}	2.03×10^{-1}
1.80×10^{-1}	1.73×10^{4}	2.63×10^{2}	1.83×10^{5}	7.41×10^{3}	3.98×10^{0}	3.33×10^{-2}	1.95×10^{-1}
2.00×10^{-1}	1.53×10^{4}	2.26×10^{2}	1.58×10^{5}	6.18×10^{3}	3.75×10^{0}	3.85×10^{-2}	1.90×10^{-1}
2.50×10^{-1}	1.16×10^{4}	1.74×10^{2}	1.13×10^{5}	4.25×10^{3}	3.27×10^{0}	5.25×10^{-2}	1.81×10^{-1}
3.00×10^{-1}	9.00×10^{3}	1.51×10^{2}	8.34×10^{4}	3.16×10^{3}	2.90×10^{0}	6.85×10^{-2}	1.85×10^{-1}
3.50×10^{-1}	7.13×10^{3}	1.40×10^{2}	6.32×10^{4}	2.48×10^{3}	2.60×10^{0}	8.66×10^{-2}	2.01×10^{-1}
4.00×10^{-1}	5.74×10^{3}	1.37×10^{2}	4.88×10^{4}	2.03×10^{3}	2.35×10^{0}	1.07×10^{-1}	2.28×10^{-1}
4.50×10^{-1}	4.69×10^{3}	1.38×10^{2}	3.82×10^{4}	1.70×10^{3}	2.13×10^{0}	1.29×10^{-1}	2.67×10^{-1}
5.00×10^{-1}	3.88×10^{3}	1.41×10^{2}	3.04×10^{4}	1.45×10^{3}	1.95×10^{0}	1.54×10^{-1}	3.20×10^{-1}
6.00×10^{-1}	2.75×10^{3}	1.55×10^{2}	1.98×10^{4}	1.12×10^{3}	1.66×10^{0}	2.11×10^{-1}	4.96×10^{-1}
7.00×10^{-1}	2.01×10^{3}	1.75×10^{2}	1.34×10^{4}	9.02×10^{2}	1.43×10^{0}	2.77×10^{-1}	8.35×10^{-1}
8.00×10^{-1}	1.52×10^{3}	1.96×10^{2}	9.38×10^{3}	7.52×10^{2}	1.26×10^{0}	3.52×10^{-1}	1.35×10^{0}
9.00×10^{-1}	1.18×10^{3}	1.87×10^{2}	6.76×10^{3}	6.42×10^{2}	1.12×10^{0}	4.37×10^{-1}	1.68×10^{0}
1.00×10^{0}	9.35×10^{2}	1.75×10^{2}	5.01×10^{3}	5.59×10^{2}	1.01×10^{0}	5.32×10^{-1}	1.79×10^{0}
1.20×10^{0}	6.20×10^{2}	1.49×10^{2}	2.93×10^{3}	4.42×10^{2}	8.48×10^{-1}	7.49×10^{-1}	1.79×10^{0}
1.40×10^{0}	4.37×10^{2}	1.29×10^{2}	1.85×10^{3}	3.64×10^{2}	7.35×10^{-1}	1.00×10^{0}	1.70×10^{0}
1.60×10^{0}	3.22×10^{2}	1.13×10^{2}	1.24×10^{3}	3.09×10^{2}	6.56×10^{-1}	1.29×10^{0}	1.68×10^{0}

TABLE 1. AIRBLAST PARAMETERS VERSUS DISTANCE FOR A ONE KILOGRAM TNT SPHERICAL AIR BURST (CONT'D)

DISTANCE (M)	INCIDENT PRESSURE (kPa)	INCIDENT IMPULSE (kPa-msec)	REFLECTED PRESSURE (kPa)	REFLECTED IMPULSE (kPa-msec)	SHOCK VELOCITY (M/msec)	ARRIVAL TIME (msec)	POSITVE PHASE DURATION (msec)
1.80×10^{0}	2.47×10^{2}	1.01×10^{2}	8.77×10^{2}	2.67×10^{2}	5.97×10^{-1}	1.60×10^{0}	1.73×10^{0}
2.00×10^{0}	1.95×10^{2}	9.21×10^{1}	6.46×10^{2}	2.36×10^{2}	5.53×10^{-1}	1.94×10^{0}	1.85×10^{0}
2.50×10^{0}	1.19×10^{2}	7.55×10^{1}	3.46×10^{2}	1.81×10^{2}	4.82×10^{-1}	2.91×10^{0}	2.36×10^{0}
3.00×10^{0}	8.16×10^{1}	6.43×10^{1}	2.15×10^{2}	1.47×10^{2}	4.42×10^{-1}	3.99×10^{0}	2.68×10^{0}
3.50×10^{0}	6.00×10^{1}	5.61×10^{1}	1.48×10^{2}	1.24×10^{2}	4.18×10^{-1}	5.16×10^{0}	2.90×10^{0}
4.00×10^{0}	4.65×10^{1}	4.98×10^{1}	1.10×10^{2}	1.06×10^{2}	4.01×10^{-1}	6.40×10^{0}	3.06×10^{0}
4.50×10^{0}	3.76×10^{1}	4.47×10^{1}	8.61×10^{1}	9.35×10^{1}	3.90×10^{-1}	7.68×10^{0}	3.21×10^{0}
5.00×10^{0}	3.13×10^{1}	4.06×10^{1}	7.00×10^{1}	8.33×10^{1}	3.83×10^{-1}	9.00×10^{0}	3.33×10^{0}
6.00×10^{0}	2.32×10^{1}	3.43×10^{1}	5.05×10^{1}	6.84×10^{1}	3.72×10^{-1}	1.17×10^{1}	3.56×10^{0}
7.00×10^{0}	1.83×10^{1}	2.97×10^{1}	3.92×10^{1}	5.80×10^{1}	3.66×10^{-1}	1.44×10^{1}	3.75×10^{0}
8.00×10^{0}	1.51×10^{1}	2.61×10^{1}	3.20×10^{1}	5.03×10^{1}	3.61×10^{-1}	1.72×10^{1}	3.92×10^{0}
9.00×10^{0}	1.28×10^{1}	2.34×10^{1}	2.70×10^{1}	4.44×10^{1}	3.58×10^{-1}	2.00×10^{1}	4.07×10^{0}
1.00×10^{1}	1.11×10^{1}	2.11×10^{1}	2.33×10^{1}	3.97×10^{1}	3.56×10^{-1}	2.27×10^{1}	4.20×10^{0}
1.20×10^{1}	8.72×10^{0}	1.77×10^{1}	1.82×10^{1}	3.28×10^{1}	3.52×10^{-1}	2.83×10^{1}	4.43×10^{0}
1.40×10^{1}	7.13×10^{0}	1.53×10^{1}	1.48×10^{1}	2.79×10^{1}	3.50×10^{-1}	3.39×10^{1}	4.64×10^{0}
1.60×10^{1}	5.99×10^{0}	1.34×10^{1}	1.23×10^{1}	2.42×10^{1}	3.49×10^{-1}	3.95×10^{1}	4.82×10^{0}
1.80×10^{1}	5.13×10^{0}	1.19×10^{1}	1.05×10^{1}	2.14×10^{1}	3.48×10^{-1}	4.52×10^{1}	4.99×10^{0}
2.00×10^{1}	4.45×10^{0}	1.08×10^{1}	9.03×10^{0}	1.92×10^{1}	3.47×10^{-1}	5.10×10^{1}	5.14×10^{0}
2.50×10^{1}	3.27×10^{0}	8.61×10^{0}	6.60×10^{0}	1.52×10^{1}	3.45×10^{-1}	6.57×10^{1}	5.47×10^{0}
3.00×10^{1}	2.53×10^{0}	7.16×10^{0}	5.12×10^{0}	1.25×10^{1}	3.44×10^{-1}	8.06×10^{1}	5.73×10^{0}
3.50×10^{1}	2.05×10^{0}	6.12×10^{0}	4.15×10^{0}	1.06×10^{1}	3.43×10^{-1}	9.54×10^{1}	5.95×10^{0}
4.00×10^{1}	1.72×10^{0}	5.30×10^{0}	3.48×10^{0}	9.16×10^{0}	3.43×10^{-1}	1.09×10^{2}	6.16×10^{0}

TABLE 2. AIRBLAST PARAMETERS VERSUS DISTANCE FOR A ONE POUND MASS TNT SPHERICAL AIR BURST

DISTANCE (Ft)	INCIDENT PRESSURE (Psi)	INCIDENT IMPULSE (Psi-msec)	REFLECTED PRESSURE (Psi)	REFLECTED IMPULSE (Psi-msec)	SHOCK VELOCITY (Ft/msec)	ARRIVAL TIME (msec)	POSITVE PHASE DURATION (msec)
1.34×10^{-1}	7.10×10^{3}	2.90×10^{2}	9.02×10^{4}	8.94×10^{3}	2.17×10^{1}	5.93×10^{-3}	
1.40×10^{-1}	6.93×10^{3}	2.70×10^{2}	8.71×10^{4}	8.12×10^{3}	2.15×10^{1}	6.18×10^{-3}	
1.60×10^{-1}	6.37×10^{3}	2.14×10^{2}	7.88×10^{4}	6.11×10^{3}	2.06×10^{1}	7.08×10^{-3}	
1.80×10^{-1}	5.87×10^{3}	1.71×10^{2}	7.20×10^{4}	4.78×10^{3}	1.98×10^{1}	8.06×10^{-3}	
2.00×10^{-1}	5.42×10^{3}	1.39×10^{2}	6.61×10^{4}	3.85×10^{3}	1.90×10^{1}	9.10×10^{-3}	
2.50×10^{-1}	4.50×10^{3}	8.79×10^{1}	5.39×10^{4}	2.47×10^{3}	1.74×10^{1}	1.19×10^{-2}	
3.00×10^{-1}	3.82×10^{3}	6.08×10^{1}	4.44×10^{4}	1.75×10^{3}	1.61×10^{1}	1.50×10^{-2}	
3.50×10^{-1}	3.29×10^{3}	4.53×10^{1}	3.71×10^{4}	1.31×10^{3}	1.50×10^{1}	1.82×10^{-2}	
4.00×10^{-1}	2.87×10^{3}	3.58×10^{1}	3.13×10^{4}	1.03×10^{3}	1.40×10^{1}	2.17×10^{-2}	1.57×10^{-1}
4.50×10^{-1}	2.53×10^{3}	2.96×10^{1}	2.68×10^{4}	8.38×10^{2}	1.31×10^{1}	2.53×10^{-2}	1.51×10^{-1}
5.00×10^{-1}	2.24×10^{3}	2.54×10^{1}	2.31×10^{4}	6.98×10^{2}	1.24×10^{1}	2.92×10^{-2}	1.46×10^{-1}
6.00×10^{-1}	1.79×10^{3}	2.04×10^{1}	1.76×10^{4}	5.14×10^{2}	1.11×10^{1}	3.76×10^{-2}	1.40×10^{-1}
7.00×10^{-1}	1.46×10^{3}	1.77×10^{1}	1.38×10^{4}	3.99×10^{2}	1.00×10^{1}	4.70×10^{-2}	1.40×10^{-1}
8.00×10^{-1}	1.20×10^{3}	1.63×10^{1}	1.10×10^{4}	3.23×10^{2}	9.15×10^{0}	5.73×10^{-2}	1.45×10^{-1}
9.00×10^{-1}	10.00×10^{2}	1.55×10^{1}	8.83×10^{3}	2.69×10^{2}	8.40×10^{0}	6.86×10^{-2}	1.57×10^{-1}
1.00×10^{0}	8.45×10^{2}	1.52×10^{1}	7.19×10^{3}	2.29×10^{2}	7.75×10^{0}	8.10×10^{-2}	1.73×10^{-1}
1.20×10^{0}	6.16×10^{2}	1.55×10^{1}	4.91×10^{3}	1.74×10^{2}	6.68×10^{0}	1.09×10^{-1}	2.24×10^{-1}
1.40×10^{0}	4.63×10^{2}	1.65×10^{1}	3.46×10^{3}	1.39×10^{2}	5.84×10^{0}	1.42×10^{-1}	3.09×10^{-1}
1.60×10^{0}	3.56×10^{2}	1.80×10^{1}	2.50×10^{3}	1.15×10^{2}	5.17×10^{0}	1.79×10^{-1}	4.54×10^{-1}
1.80×10^{0}	2.80×10^{2}	1.98×10^{1}	1.85×10^{3}	9.78×10^{1}	4.62×10^{0}	2.20×10^{-1}	6.91×10^{-1}
2.00×10^{0}	2.25×10^{2}	2.18×10^{1}	1.39×10^{3}	8.47×10^{1}	4.17×10^{0}	2.66×10^{-1}	1.01×10^{0}
2.50×10^{0}	1.38×10^{2}	1.96×10^{1}	7.44×10^{2}	6.30×10^{1}	3.35×10^{0}	4.02×10^{-1}	1.37×10^{0}
3.00×10^{0}	9.17×10^{1}	1.67×10^{1}	4.36×10^{2}	4.98×10^{1}	2.80×10^{0}	5.66×10^{-1}	1.38×10^{0}
3.50×10^{0}	6.45×10^{1}	1.44×10^{1}	2.75×10^{2}	4.10×10^{1}	2.43×10^{0}	7.57×10^{-1}	1.31×10^{0}
4.00×10^{0}	4.76×10^{1}	1.27×10^{1}	1.85×10^{2}	3.47×10^{1}	2.17×10^{0}	9.73×10^{-1}	1.29×10^{0}

TABLE 2. AIRBLAST PARAMETERS VERSUS DISTANCE FOR A ONE POUND MASS TNT SPHERICAL AIR BURST (CONT'D)

DISTANCE (Ft)	INCIDENT PRESSURE (Psi)	INCIDENT IMPULSE (Psi-msec)	REFLECTED PRESSURE (Psi)	REFLECTED IMPULSE (Psi-msec)	SHOCK VELOCITY (Ft/msec)	ARRIVAL TIME (msec)	POSITVE PHASE DURATION (msec)
4.50×10^{0}	3.64×10^{1}	1.14×10^{1}	1.30×10^{2}	3.01×10^{1}	1.97×10^{0}	1.21×10^{0}	1.32×10^{0}
5.00×10^{0}	2.88×10^{1}	1.03×10^{1}	9.59×10^{1}	2.65×10^{1}	1.83×10^{0}	1.47×10^{0}	1.41×10^{0}
6.00×10^{0}	1.93×10^{1}	8.79×10^{0}	5.74×10^{1}	2.14×10^{1}	1.63×10^{0}	2.05×10^{0}	1.73×10^{0}
7.00×10^{0}	1.39×10^{1}	7.67×10^{0}	3.81×10^{1}	1.79×10^{1}	1.50×10^{0}	2.68×10^{0}	1.97×10^{0}
8.00×10^{0}	1.06×10^{1}	6.82×10^{0}	2.72×10^{1}	1.54×10^{1}	1.42×10^{0}	3.37×10^{0}	2.13×10^{0}
9.00×10^{0}	8.37×10^{0}	6.14×10^{0}	2.06×10^{1}	1.35×10^{1}	1.36×10^{0}	4.09×10^{0}	2.25×10^{0}
1.00×10^{1}	6.86×10^{0}	5.59×10^{0}	1.63×10^{1}	1.20×10^{1}	1.32×10^{0}	4.85×10^{0}	2.35×10^{0}
1.20×10^{1}	4.94×10^{0}	4.74×10^{0}	1.12×10^{1}	9.80×10^{0}	1.27×10^{0}	6.42×10^{0}	2.52×10^{0}
1.40×10^{1}	3.81×10^{0}	4.11×10^{0}	8.37×10^{0}	8.28×10^{0}	1.23×10^{0}	8.05×10^{0}	2.66×10^{0}
1.60×10^{1}	3.08×10^{0}	3.62×10^{0}	6.66×10^{0}	7.17×10^{0}	1.21×10^{0}	9.71×10^{0}	2.79×10^{0}
1.80×10^{1}	2.58×10^{0}	3.24×10^{0}	5.52×10^{0}	6.32×10^{0}	1.20×10^{0}	1.14×10^{1}	2.90×10^{0}
2.00×10^{1}	2.21×10^{0}	2.94×10^{0}	4.70×10^{0}	5.65×10^{0}	1.19×10^{0}	1.31×10^{1}	3.00×10^{0}
2.50×10^{1}	1.63×10^{0}	2.37×10^{0}	3.42×10^{0}	4.46×10^{0}	1.17×10^{0}	1.73×10^{1}	3.22×10^{0}
3.00×10^{1}	1.28×10^{0}	1.99×10^{0}	2.67×10^{0}	3.69×10^{0}	1.16×10^{0}	2.15×10^{1}	3.40×10^{0}
3.50×10^{1}	1.05×10^{0}	1.72×10^{0}	2.17×10^{0}	3.14×10^{0}	1.15×10^{0}	2.58×10^{1}	3.56×10^{0}
4.00×10^{1}	8.79×10^{-1}	1.51×10^{0}	1.81×10^{0}	2.73×10^{0}	1.14×10^{0}	3.01×10^{1}	3.70×10^{0}
4.50×10^{1}	7.52×10^{-1}	1.34×10^{0}	1.53×10^{0}	2.41×10^{0}	1.14×10^{0}	3.44×10^{1}	3.82×10^{0}
5.00×10^{1}	6.53×10^{-1}	1.21×10^{0}	1.33×10^{0}	2.16×10^{0}	1.14×10^{0}	3.88×10^{1}	3.94×10^{0}
6.00×10^{1}	5.08×10^{-1}	1.01×10^{0}	1.03×10^{0}	1.78×10^{0}	1.13×10^{0}	4.77×10^{1}	4.15×10^{0}
7.00×10^{1}	4.10×10^{-1}	8.63×10^{-1}	8.26×10^{-1}	1.51×10^{0}	1.13×10^{0}	5.68×10^{1}	4.32×10^{0}
8.00×10^{1}	3.40×10^{-1}	7.54×10^{-1}	6.87×10^{-1}	1.31×10^{0}	1.13×10^{0}	6.59×10^{1}	4.46×10^{0}
9.00×10^{1}	2.89×10^{-1}	6.67×10^{-1}	5.86×10^{-1}	1.15×10^{0}	1.13×10^{0}	7.48×10^{1}	4.60×10^{0}
1.00×10^{2}	2.52×10^{-1}	5.96×10^{-1}	5.10×10^{-1}	1.03×10^{0}	1.13×10^{0}	8.34×10^{1}	4.73×10^{0}

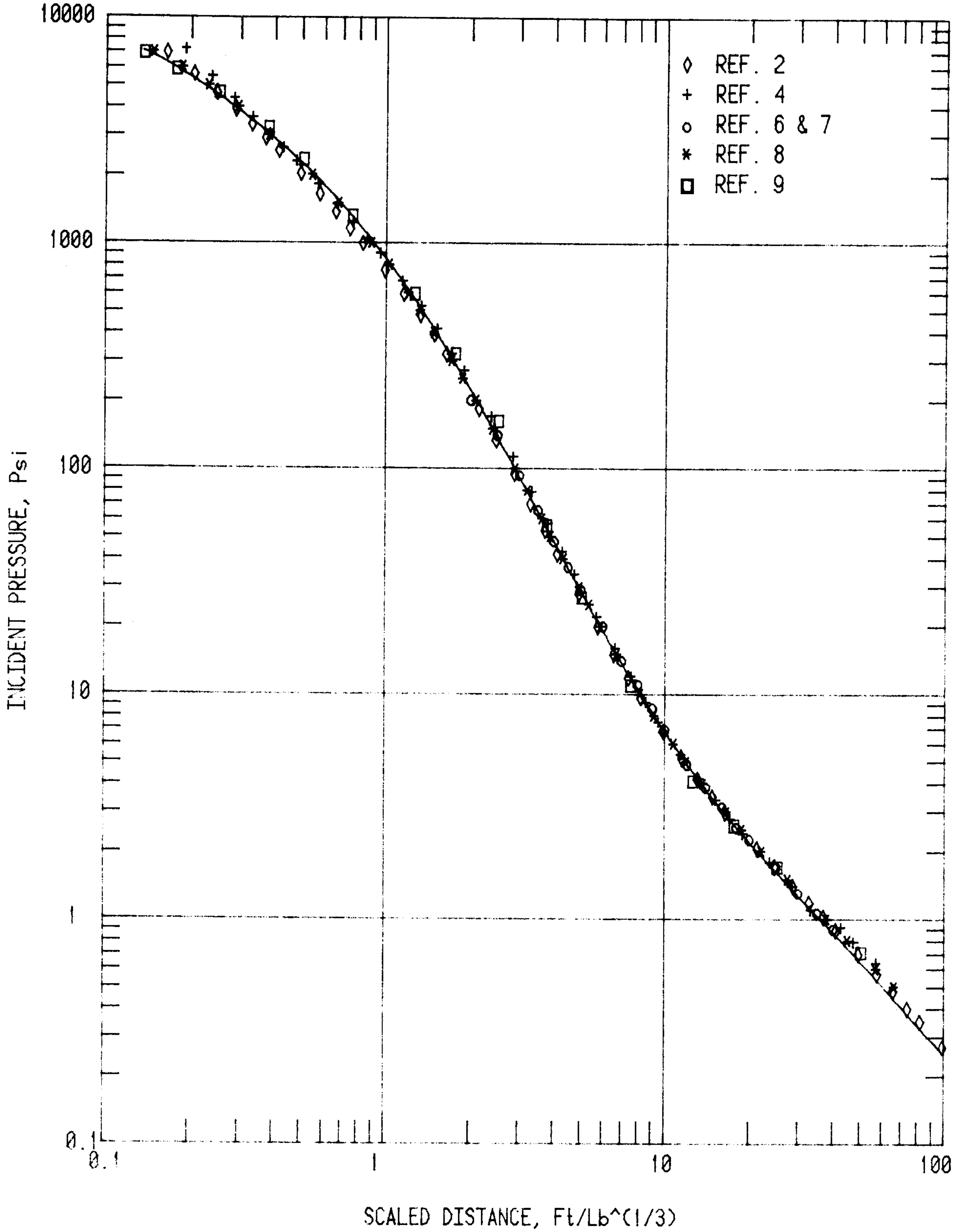

Figure 2. Comparison of New Curve of Incident Pressure versus Scaled Distance with other Sources.

3. Shock Arrival Time. The shock arrival time is one of the blast parameters that can be recorded by different methods and is usually one of the more accurate measurements. Here again data from many sources were used to generate the functions in a polynomial equation. In order to assure consistency between the arrival time, the shock front velocity and the peak overpressure, the shock front velocity determined from Equation (12) was integrated as shown in Equation (13) to calculate the arrival time.

$$t_{a1} = \int_{\lambda_o}^{\lambda_1} \frac{d}{U} + 0.00593, \tag{13}$$

where λ_o = charge radius 0.134 $ft/lb^{1/3}$ for 1 lbm,

λ_1 = distance ($ft/lb^{1/3}$) for arrival time computation, and

U = shock front velocity

0.00593 msec = arrival time at charge surface.

The arrival times calculated from Equation (13) were used as input to the polynomial fitting program, and an equation describing the arrival time versus distance is presented in Appendix A. The computed values are listed in Tables 1 and 2. The solid curve presented in Figure 3 represents the values from Table 2. Also presented in Figure 3 are data from several sources showing the comparison of data with the fitted curve. Data from Reference 8 was omitted because there is evidently an error in the tables listing time of arrival versus peak overpressure for a spherical TNT charge of one pound mass. Polynomial equations and curve plots are presented in Appendix A for both Metric and English units.

4. Incident Impulse. The incident impulse as shown in Figure 1 is determined from the integration of the overpressure versus time as recorded from a pressure transducer. At scaled distances less than 1 the measured values of incident impulse are very few and sometimes of suspect quality. References 2, 6, 7, 8, and 9 were used for input data in establishing the polynomial equations for incident impulse versus scaled distance presented in Appendix A.

The output from the equation is presented in tabular form in Tables 1 and 2 and is the solid line in Figure 4. The major differences between the different sources appear between a scaled distance of 1 $ft/lbm^{1/3}$ and 3 $ft/lbm^{1/3}$.

5. Positive Duration. The duration (t_{+1}) of the blast wave is shown in Figure 1. Here again a record of the overpressure versus time is required to determine the duration of the blast wave. When recording peak overpressures in the range of 10,000 kPa and a negative pressure of less than 100 kPa, then it is very difficult to determine the time of which the overpressure changes to an underpressure. There can be large variations in individual interpretations of the positive duration of the blast wave. In Figure 5 the change in slope at a scaled distance of 1.2 is well documented for hemispherical surface bursts as well as free-air code calculations, but most free-air experimental data tends to show a continued downward trend.

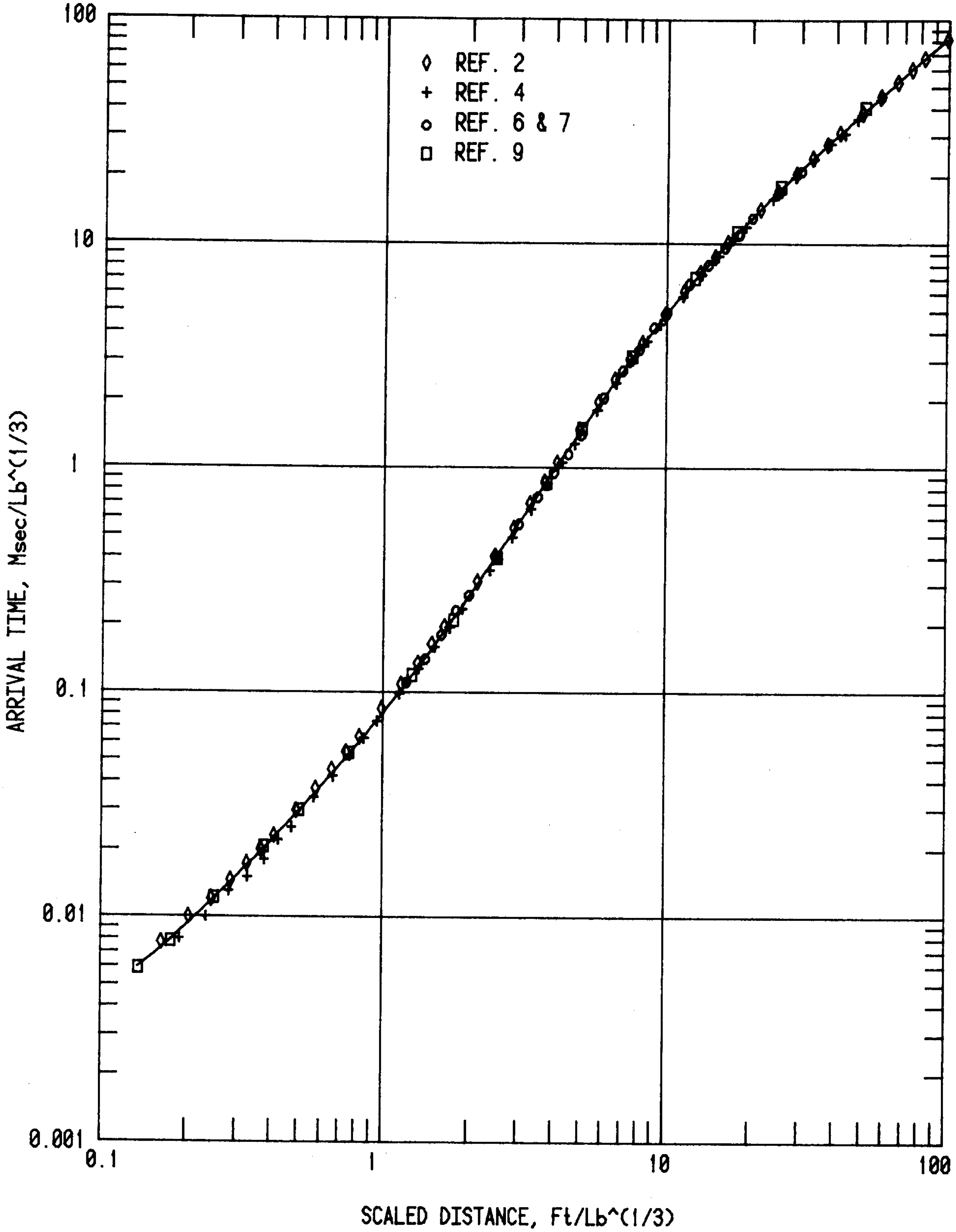

Figure 3. Comparison of New Curve of Scaled Arrival Time versus Scaled Distance with other Sources.

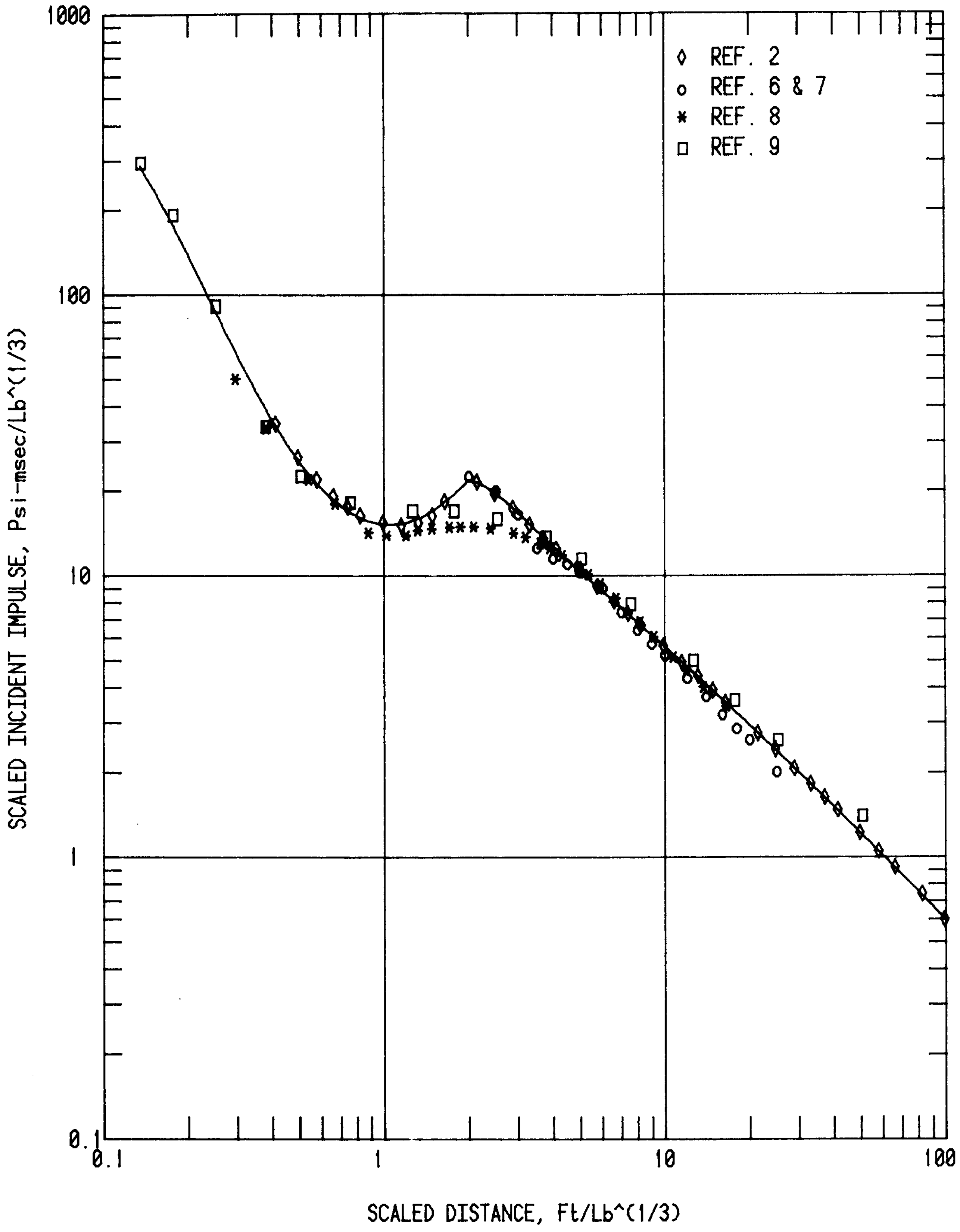

Figure 4. Comparison of New Curve of Scaled Incident Impulse versus Scaled Distance with other Sources.

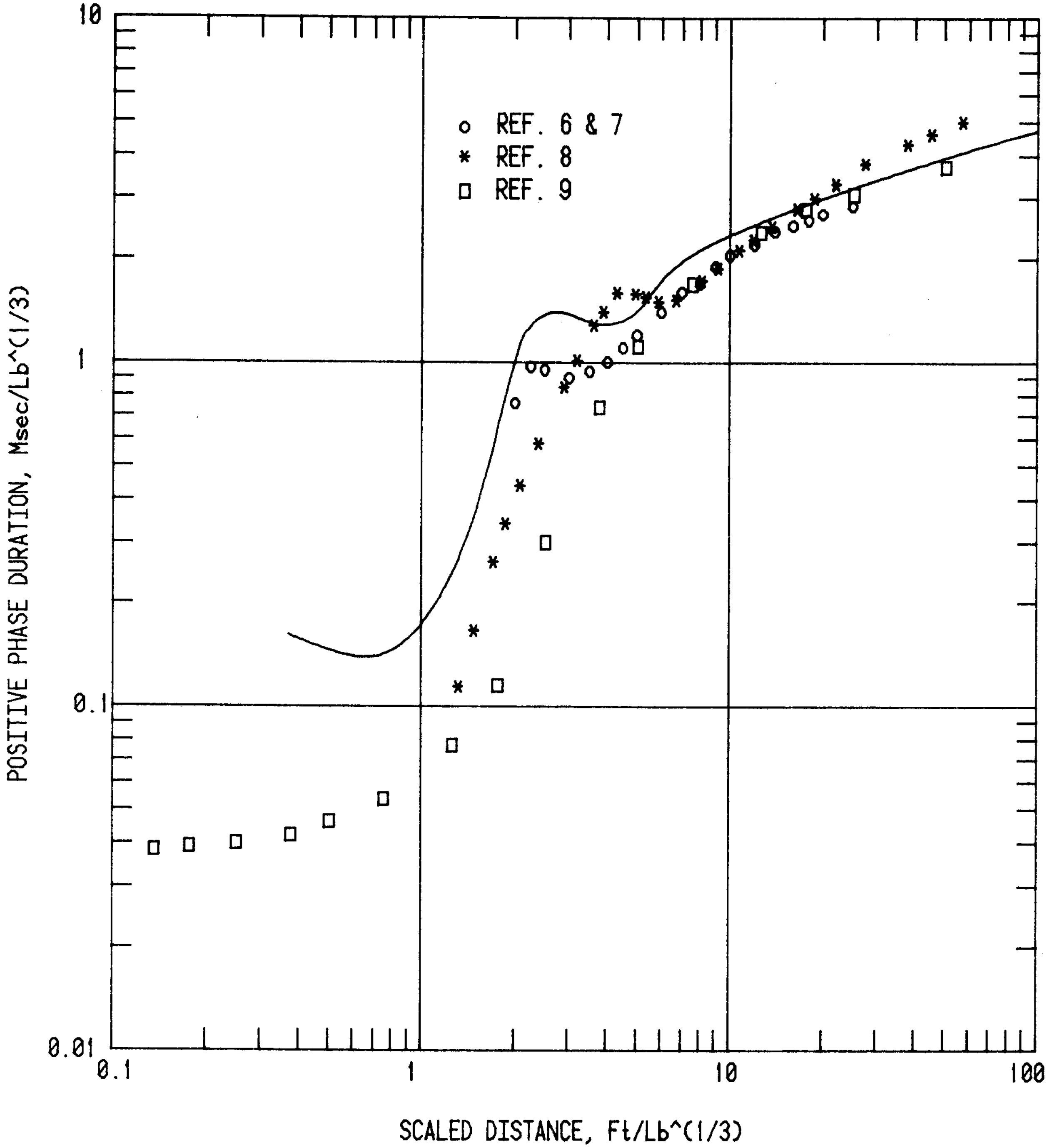

Figure 5. Comparison of New Curve of Scaled Positive Duration versus Scaled Distance with other Sources.

Data points listed in Tables 1 and 2 were computed from equations developed in Appendix A. These computations are based on hemispherical data using a 1.8 reflection factor. The results are represented by the solid curve in Figure 5. Data from other sources show the large scatter typical in duration measurements.

6. Reflected Overpressure. The reflected overpressure presented in this report was developed primarily from the incident overpressure using Equation (10). Presenting the reflected pressure in this manner assures a consistency with the incident peak overpressure. Data points from References 4, 6, 7, 8, 11, and 14 are plotted on a curve developed from the functional equation in Appendix A. The new standard curve with data points from other sources is presented in Figure 6.

7. Reflected Impulse. The reflected impulse from a TNT spherical charge detonated in free-air can only be measured when the blast wave is reflected from a rigid surface. The available data is quite limited for TNT; and therefore, one of the primary data sources used in developing the reflected impulse curve came from Reference 4, which is compiled data on Pentolite spheres. Data from References 6 and 7 were also used. A polynomial fit was made to the data, and the equations are presented in Appendix A. The outputs from the equations are listed in Tables 1 and 2. Listings from Table 2 are plotted in Figure 7 along with some other sources of information. There is a large change between the present curve and the curve now in Reference 1.

C. Hemispherical TNT Surface Burst

The peak overpressure, shock velocity, shock arrival time, incident impulse, and positive duration presented in this section are based on data tables and curves presented in Reference 2. The peak overpressure, arrival time and shock velocity were extrapolated from a scaled distance 0.07934 $m/kg^{1/3}$ (0.2 $ft/lbm^{1/3}$) into the surface of the charge 0.06744 $m/kg^{1/3}$ (0.170 $ft/lbm^{1/3}$) based on a density of 1.57 gm/cm^3 (98 lbm/ft^3). The incident impulse was extrapolated from a scaled distance of 0.198 $m/kg^{1/3}$ (0.5 $ft/lbm^{1/3}$) to the surface of the charge. The duration of the wave was not extrapolated or amended. The reflected pressure values were calculated from the incident pressure values using Equation (8). The reflected impulse presented in this section was developed from the spherical free-air data by using a 1.8 yield reflection factor for a hemispherical surface burst.

The airblast parameters discussed above have been fitted to polynomial equations for both Metric and English units and are presented in Appendix B. The outputs from the equations have been listed at selected scaled distances in Tables 3 and 4. The plots of blast parameters versus scaled distances in Metric and English units are presented in Appendix B.

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[14] *W.H. Jack, Jr. and B.F. Armendt, Jr. "Measurements of Normally Reflected Shock Parameters from Explosive Charges under Simulated High Altitude Conditions," BRL Report No. 1280, April 1965 (AD 469014)*

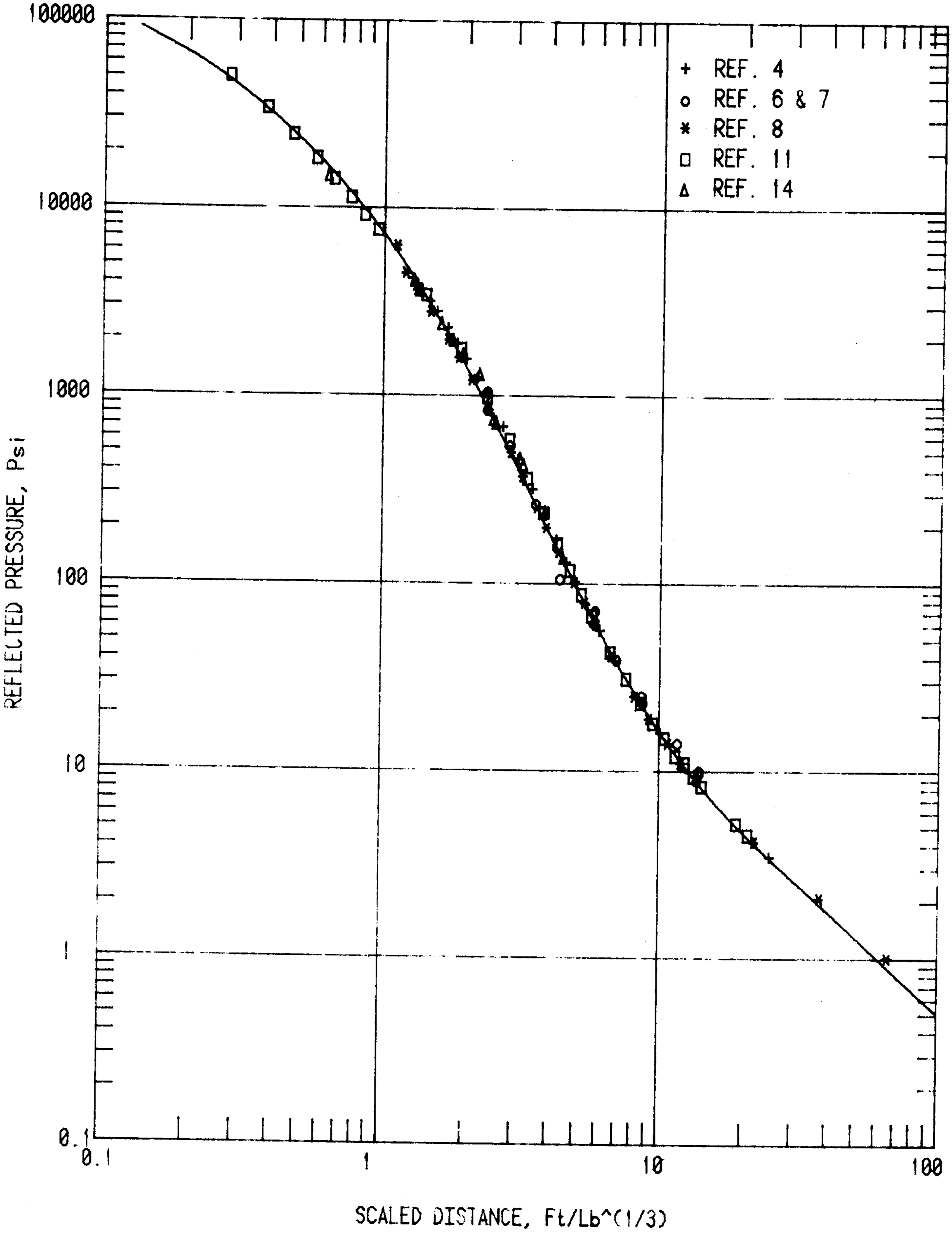

Figure 6. Comparison of New Curve of Reflected Pressure versus Scaled Distance with other Sources.

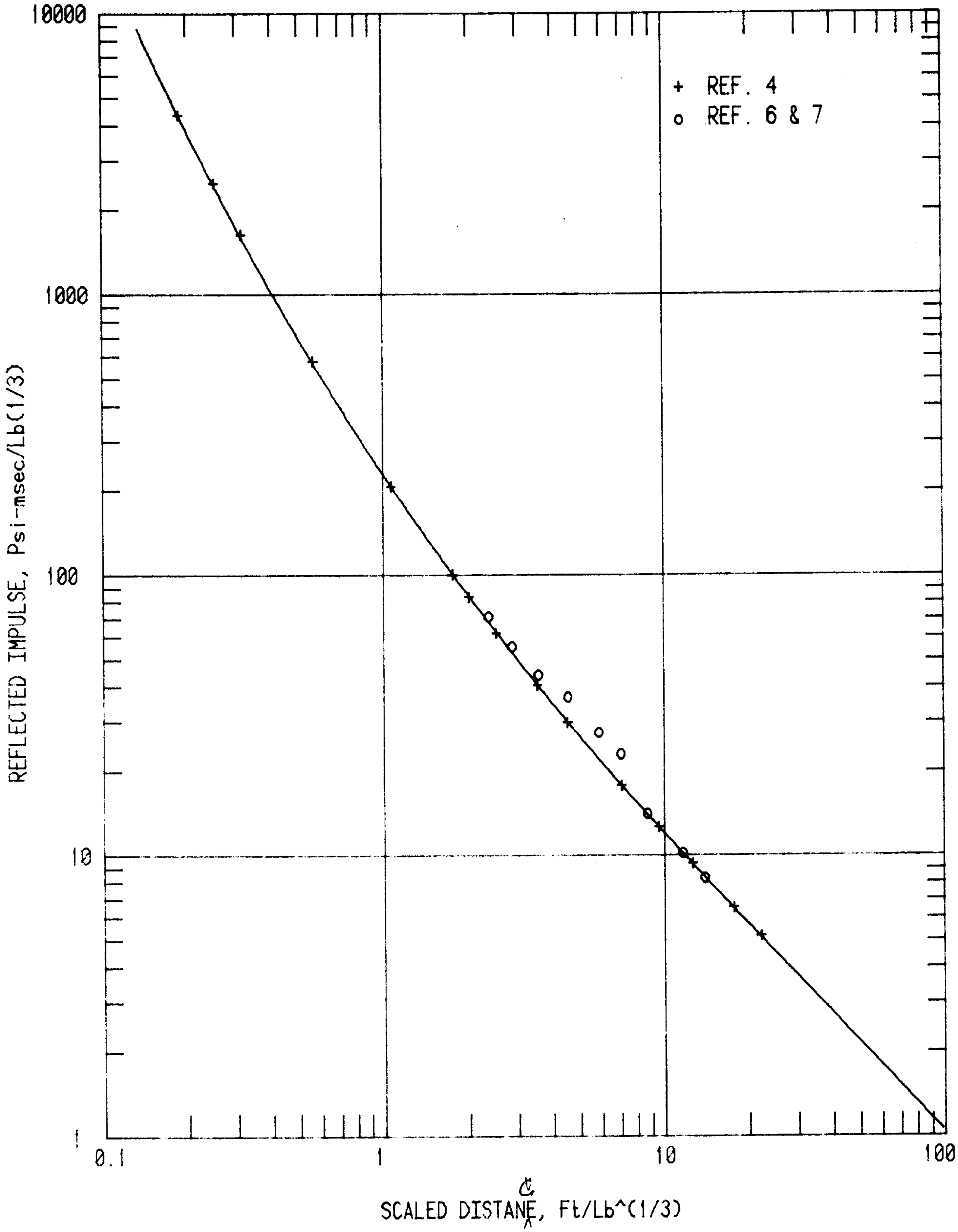

Figure 7. Comparison of New Curve of Scaled Reflected Impulse versus Scaled Distance with other Sources.

TABLE 3. AIRBLAST PARAMETERS VERSUS DISTANCE FOR A ONE KILOGRAM TNT HEMISPHERICAL SURFACE BURST

DISTANCE (M)	INCIDENT PRESSURE (kPa)	INCIDENT IMPULSE (kPa-msec)	REFLECTED PRESSURE (kPa)	REFLECTED IMPULSE (kPa-msec)	SHOCK VELOCITY (M/msec)	ARRIVAL TIME (msec)	POSITVE PHASE DURATION (msec)
6.74×10^{-2}	5.54×10^{4}	2.96×10^{3}	7.33×10^{5}	8.69×10^{4}	7.03×10^{0}	1.07×10^{-2}	
7.00×10^{-2}	5.36×10^{4}	2.78×10^{3}	7.00×10^{5}	8.02×10^{4}	6.93×10^{0}	1.11×10^{-2}	
8.00×10^{-2}	4.76×10^{4}	2.18×10^{3}	5.97×10^{5}	6.06×10^{4}	6.53×10^{0}	1.25×10^{-2}	
9.00×10^{-2}	4.26×10^{4}	1.74×10^{3}	5.23×10^{5}	4.76×10^{4}	6.17×10^{0}	1.40×10^{-2}	
1.00×10^{-1}	3.85×10^{4}	1.40×10^{3}	4.64×10^{5}	3.85×10^{4}	5.86×10^{0}	1.56×10^{-2}	
1.20×10^{-1}	3.18×10^{4}	9.67×10^{2}	3.76×10^{5}	2.69×10^{4}	5.35×10^{0}	1.92×10^{-2}	
1.40×10^{-1}	2.67×10^{4}	7.08×10^{2}	3.10×10^{5}	2.01×10^{4}	4.93×10^{0}	2.31×10^{-2}	
1.60×10^{-1}	2.28×10^{4}	5.47×10^{2}	2.59×10^{5}	1.57×10^{4}	4.57×10^{0}	2.74×10^{-2}	
1.80×10^{-1}	1.97×10^{4}	4.41×10^{2}	2.18×10^{5}	1.27×10^{4}	4.27×10^{0}	3.21×10^{-2}	2.57×10^{-1}
2.00×10^{-1}	1.73×10^{4}	3.69×10^{2}	1.86×10^{5}	1.05×10^{4}	4.00×10^{0}	3.70×10^{-2}	2.43×10^{-1}
2.50×10^{-1}	1.30×10^{4}	2.66×10^{2}	1.31×10^{5}	7.16×10^{3}	3.47×10^{0}	5.06×10^{-2}	2.28×10^{-1}
3.00×10^{-1}	1.02×10^{4}	2.16×10^{2}	9.70×10^{4}	5.29×10^{3}	3.08×10^{0}	6.58×10^{-2}	2.23×10^{-1}
3.50×10^{-1}	8.26×10^{3}	1.89×10^{2}	7.48×10^{4}	4.12×10^{3}	2.78×10^{0}	8.26×10^{-2}	2.24×10^{-1}
4.00×10^{-1}	6.83×10^{3}	1.75×10^{2}	5.94×10^{4}	3.34×10^{3}	2.54×10^{0}	1.01×10^{-1}	2.33×10^{-1}
4.50×10^{-1}	5.74×10^{3}	1.68×10^{2}	4.81×10^{4}	2.78×10^{3}	2.34×10^{0}	1.21×10^{-1}	2.52×10^{-1}
5.00×10^{-1}	4.87×10^{3}	1.66×10^{2}	3.95×10^{4}	2.37×10^{3}	2.17×10^{0}	1.43×10^{-1}	2.81×10^{-1}
6.00×10^{-1}	3.61×10^{3}	1.71×10^{2}	2.75×10^{4}	1.81×10^{3}	1.89×10^{0}	1.93×10^{-1}	3.79×10^{-1}
7.00×10^{-1}	2.75×10^{3}	1.83×10^{2}	1.97×10^{4}	1.45×10^{3}	1.66×10^{0}	2.50×10^{-1}	5.48×10^{-1}
8.00×10^{-1}	2.14×10^{3}	2.01×10^{2}	1.44×10^{4}	1.20×10^{3}	1.48×10^{0}	3.14×10^{-1}	8.15×10^{-1}
9.00×10^{-1}	1.69×10^{3}	2.24×10^{2}	1.07×10^{4}	1.02×10^{3}	1.32×10^{0}	3.87×10^{-1}	7.42×10^{-1}
1.00×10^{0}	1.36×10^{3}	2.36×10^{2}	8.14×10^{3}	8.85×10^{2}	1.20×10^{0}	4.68×10^{-1}	1.71×10^{0}
1.20×10^{0}	9.13×10^{2}	2.14×10^{2}	4.90×10^{3}	6.94×10^{2}	10.00×10^{-1}	6.53×10^{-1}	2.17×10^{0}
1.40×10^{0}	6.45×10^{2}	1.89×10^{2}	3.11×10^{3}	5.69×10^{2}	8.60×10^{-1}	8.70×10^{-1}	2.20×10^{0}
1.60×10^{0}	4.75×10^{2}	1.67×10^{2}	2.08×10^{3}	4.80×10^{2}	7.59×10^{-1}	1.12×10^{0}	2.11×10^{0}
1.80×10^{0}	3.62×10^{2}	1.49×10^{2}	1.45×10^{3}	4.14×10^{2}	6.83×10^{-1}	1.39×10^{0}	2.04×10^{0}

TABLE 3. AIRBLAST PARAMETERS VERSUS DISTANCE FOR A ONE KILOGRAM TNT HEMISPHERICAL SURFACE BURST (CONT'D)

DISTANCE (M)	INCIDENT PRESSURE (kPa)	INCIDENT IMPULSE (kPa-msec)	REFLECTED PRESSURE (kPa)	REFLECTED IMPULSE (kPa-msec)	SHOCK VELOCITY (M/msec)	ARRIVAL TIME (msec)	POSITIVE PHASE DURATION (msec)
2.00×10^{0}	2.84×10^{2}	1.34×10^{2}	1.06×10^{3}	3.64×10^{2}	6.26×10^{-1}	1.70×10^{0}	2.05×10^{0}
2.50×10^{0}	1.72×10^{2}	1.09×10^{2}	5.48×10^{2}	2.78×10^{2}	5.33×10^{-1}	2.56×10^{0}	2.36×10^{0}
3.00×10^{0}	1.16×10^{2}	9.27×10^{1}	3.31×10^{2}	2.24×10^{2}	4.79×10^{-1}	3.54×10^{0}	2.83×10^{0}
3.50×10^{0}	8.43×10^{1}	8.10×10^{1}	2.23×10^{2}	1.88×10^{2}	4.46×10^{-1}	4.63×10^{0}	3.17×10^{0}
4.00×10^{0}	6.49×10^{1}	7.21×10^{1}	1.62×10^{2}	1.61×10^{2}	4.24×10^{-1}	5.78×10^{0}	3.42×10^{0}
4.50×10^{0}	5.21×10^{1}	6.51×10^{1}	1.25×10^{2}	1.41×10^{2}	4.09×10^{-1}	6.99×10^{0}	3.62×10^{0}
5.00×10^{0}	4.32×10^{1}	5.93×10^{1}	1.01×10^{2}	1.26×10^{2}	3.98×10^{-1}	8.24×10^{0}	3.79×10^{0}
6.00×10^{0}	3.17×10^{1}	5.03×10^{1}	7.13×10^{1}	1.03×10^{2}	3.83×10^{-1}	1.08×10^{1}	4.05×10^{0}
7.00×10^{0}	2.49×10^{1}	4.36×10^{1}	5.47×10^{1}	8.69×10^{1}	3.74×10^{-1}	1.35×10^{1}	4.26×10^{0}
8.00×10^{0}	2.03×10^{1}	3.84×10^{1}	4.41×10^{1}	7.53×10^{1}	3.68×10^{-1}	1.62×10^{1}	4.45×10^{0}
9.00×10^{0}	1.72×10^{1}	3.43×10^{1}	3.68×10^{1}	6.64×10^{1}	3.64×10^{-1}	1.89×10^{1}	4.63×10^{0}
1.00×10^{1}	1.48×10^{1}	3.10×10^{1}	3.15×10^{1}	5.93×10^{1}	3.61×10^{-1}	2.16×10^{1}	4.79×10^{0}
1.20×10^{1}	1.16×10^{1}	2.60×10^{1}	2.44×10^{1}	4.89×10^{1}	3.57×10^{-1}	2.72×10^{1}	5.08×10^{0}
1.40×10^{1}	9.49×10^{0}	2.24×10^{1}	1.98×10^{1}	4.16×10^{1}	3.54×10^{-1}	3.28×10^{1}	5.33×10^{0}
1.60×10^{1}	8.02×10^{0}	1.97×10^{1}	1.66×10^{1}	3.62×10^{1}	3.52×10^{-1}	3.84×10^{1}	5.56×10^{0}
1.80×10^{1}	6.92×10^{0}	1.76×10^{1}	1.42×10^{1}	3.20×10^{1}	3.50×10^{-1}	4.41×10^{1}	5.76×10^{0}
2.00×10^{1}	6.07×10^{0}	1.59×10^{1}	1.24×10^{1}	2.87×10^{1}	3.49×10^{-1}	4.99×10^{1}	5.94×10^{0}
2.50×10^{1}	4.56×10^{0}	1.28×10^{1}	9.29×10^{0}	2.27×10^{1}	3.47×10^{-1}	6.44×10^{1}	6.31×10^{0}
3.00×10^{1}	3.56×10^{0}	1.06×10^{1}	7.24×10^{0}	1.88×10^{1}	3.45×10^{-1}	7.89×10^{1}	6.61×10^{0}
3.50×10^{1}	2.86×10^{0}	9.08×10^{0}	5.79×10^{0}	1.60×10^{1}	3.44×10^{-1}	9.33×10^{1}	6.88×10^{0}
4.00×10^{1}	2.36×10^{0}	7.92×10^{0}	4.77×10^{0}	1.39×10^{1}	3.44×10^{-1}	1.08×10^{2}	7.15×10^{0}

TABLE 4. AIRBLAST PARAMETERS VERSUS DISTANCE FOR A ONE POUND MASS TNT HEMISPHERICAL SURFACE BURST

DISTANCE (Ft)	INCIDENT PRESSURE (Psi)	INCIDENT IMPULSE (Psi-msec)	REFLECTED PRESSURE (Psi)	REFLECTED IMPULSE (Psi-msec)	SHOCK VELOCITY (Ft/msec)	ARRIVAL TIME (msec)	POSITVE PHASE DURATION (msec)
1.70×10^{-1}	8.04×10^{3}	3.30×10^{2}	1.06×10^{5}	9.67×10^{3}	2.31×10^{1}	8.23×10^{-3}	
1.80×10^{-1}	7.64×10^{3}	2.99×10^{2}	9.91×10^{4}	8.56×10^{3}	2.25×10^{1}	8.65×10^{-3}	
2.00×10^{-1}	6.96×10^{3}	2.47×10^{2}	8.75×10^{4}	6.87×10^{3}	2.15×10^{1}	9.51×10^{-3}	
2.50×10^{-1}	5.63×10^{3}	1.59×10^{2}	6.80×10^{4}	4.36×10^{3}	1.93×10^{1}	1.19×10^{-2}	
3.00×10^{-1}	4.65×10^{3}	1.10×10^{2}	5.51×10^{4}	3.05×10^{3}	1.76×10^{1}	1.46×10^{-2}	
3.50×10^{-1}	3.91×10^{3}	8.02×10^{1}	4.55×10^{4}	2.28×10^{3}	1.62×10^{1}	1.76×10^{-2}	
4.00×10^{-1}	3.34×10^{3}	6.19×10^{1}	3.80×10^{4}	1.78×10^{3}	1.51×10^{1}	2.09×10^{-2}	
4.50×10^{-1}	2.89×10^{3}	4.99×10^{1}	3.20×10^{4}	1.43×10^{3}	1.41×10^{1}	2.44×10^{-2}	1.99×10^{-1}
5.00×10^{-1}	2.54×10^{3}	4.17×10^{1}	2.73×10^{4}	1.19×10^{3}	1.32×10^{1}	2.81×10^{-2}	1.88×10^{-1}
6.00×10^{-1}	2.01×10^{3}	3.16×10^{1}	2.05×10^{4}	8.67×10^{2}	1.18×10^{1}	3.62×10^{-2}	1.77×10^{-1}
7.00×10^{-1}	1.64×10^{3}	2.61×10^{1}	1.60×10^{4}	6.69×10^{2}	1.06×10^{1}	4.52×10^{-2}	1.72×10^{-1}
8.00×10^{-1}	1.37×10^{3}	2.28×10^{1}	1.28×10^{4}	5.37×10^{2}	9.74×10^{0}	5.49×10^{-2}	1.71×10^{-1}
9.00×10^{-1}	1.16×10^{3}	2.08×10^{1}	1.05×10^{4}	4.45×10^{2}	9.01×10^{0}	6.54×10^{-2}	1.73×10^{-1}
1.00×10^{0}	1.00×10^{3}	1.96×10^{1}	8.74×10^{3}	3.77×10^{2}	8.39×10^{0}	7.67×10^{-2}	1.79×10^{-1}
1.20×10^{0}	7.63×10^{2}	1.86×10^{1}	6.28×10^{3}	2.85×10^{2}	7.39×10^{0}	1.02×10^{-1}	2.04×10^{-1}
1.40×10^{0}	5.97×10^{2}	1.87×10^{1}	4.67×10^{3}	2.26×10^{2}	6.59×10^{0}	1.30×10^{-1}	2.52×10^{-1}
1.60×10^{0}	4.75×10^{2}	1.94×10^{1}	3.54×10^{3}	1.86×10^{2}	5.93×10^{0}	1.63×10^{-1}	3.29×10^{-1}
1.80×10^{0}	3.84×10^{2}	2.07×10^{1}	2.73×10^{3}	1.57×10^{2}	5.36×10^{0}	1.98×10^{-1}	4.45×10^{-1}
2.00×10^{0}	3.15×10^{2}	2.23×10^{1}	2.13×10^{3}	1.35×10^{2}	4.89×10^{0}	2.38×10^{-1}	6.10×10^{-1}
2.50×10^{0}	2.00×10^{2}	2.64×10^{1}	1.21×10^{3}	9.97×10^{1}	3.96×10^{0}	3.54×10^{-1}	1.28×10^{0}
3.00×10^{0}	1.35×10^{2}	2.40×10^{1}	7.27×10^{2}	7.82×10^{1}	3.31×10^{0}	4.94×10^{-1}	1.66×10^{0}
3.50×10^{0}	9.53×10^{1}	2.12×10^{1}	4.63×10^{2}	6.40×10^{1}	2.84×10^{0}	6.58×10^{-1}	1.70×10^{0}
4.00×10^{0}	7.02×10^{1}	1.87×10^{1}	3.09×10^{2}	5.40×10^{1}	2.51×10^{0}	8.45×10^{-1}	1.62×10^{0}
4.50×10^{0}	5.35×10^{1}	1.67×10^{1}	2.16×10^{2}	4.66×10^{1}	2.26×10^{0}	1.05×10^{0}	1.57×10^{0}
5.00×10^{0}	4.19×10^{1}	1.51×10^{1}	1.57×10^{2}	4.10×10^{1}	2.07×10^{0}	1.28×10^{0}	1.57×10^{0}

TABLE 4. AIRBLAST PARAMETERS VERSUS DISTANCE FOR A ONE POUND MASS TNT HEMISPHERICAL SURFACE BURST (CONT'D)

DISTANCE (Ft)	INCIDENT PRESSURE (Psi)	INCIDENT IMPULSE (Psi-msec)	REFLECTED PRESSURE (Psi)	REFLECTED IMPULSE (Psi-msec)	SHOCK VELOCITY (Ft/msec)	ARRIVAL TIME (msec)	POSITVE PHASE DURATION (msec)
6.00×10^{0}	2.77×10^{1}	1.27×10^{1}	9.15×10^{1}	3.28×10^{1}	1.81×10^{0}	1.80×10^{0}	1.70×10^{0}
7.00×10^{0}	1.98×10^{1}	1.11×10^{1}	5.91×10^{1}	2.74×10^{1}	1.64×10^{0}	2.37×10^{0}	2.03×10^{0}
8.00×10^{0}	1.49×10^{1}	9.84×10^{0}	4.14×10^{1}	2.34×10^{1}	1.53×10^{0}	3.00×10^{0}	2.28×10^{0}
9.00×10^{0}	1.17×10^{1}	8.88×10^{0}	3.08×10^{1}	2.04×10^{1}	1.45×10^{0}	3.68×10^{0}	2.47×10^{0}
1.00×10^{1}	9.56×10^{0}	8.10×10^{0}	2.40×10^{1}	1.81×10^{1}	1.39×10^{0}	4.38×10^{0}	2.62×10^{0}
1.20×10^{1}	6.83×10^{0}	6.90×10^{0}	1.61×10^{1}	1.48×10^{1}	1.32×10^{0}	5.87×10^{0}	2.85×10^{0}
1.40×10^{1}	5.23×10^{0}	6.01×10^{0}	1.19×10^{1}	1.25×10^{1}	1.28×10^{0}	7.43×10^{0}	3.03×10^{0}
1.60×10^{1}	4.21×10^{0}	5.32×10^{0}	9.36×10^{0}	1.08×10^{1}	1.25×10^{0}	9.02×10^{0}	3.17×10^{0}
1.80×10^{1}	3.50×10^{0}	4.77×10^{0}	7.67×10^{0}	9.48×10^{0}	1.22×10^{0}	1.06×10^{1}	3.30×10^{0}
2.00×10^{1}	2.99×10^{0}	4.31×10^{0}	6.48×10^{0}	8.46×10^{0}	1.21×10^{0}	1.23×10^{1}	3.41×10^{0}
2.50×10^{1}	2.17×10^{0}	3.48×10^{0}	4.63×10^{0}	6.67×10^{0}	1.18×10^{0}	1.64×10^{1}	3.67×10^{0}
3.00×10^{1}	1.70×10^{0}	2.92×10^{0}	3.58×10^{0}	5.50×10^{0}	1.17×10^{0}	2.07×10^{1}	3.89×10^{0}
3.50×10^{1}	1.39×10^{0}	2.52×10^{0}	2.90×10^{0}	4.68×10^{0}	1.16×10^{0}	2.49×10^{1}	4.09×10^{0}
4.00×10^{1}	1.18×10^{0}	2.21×10^{0}	2.43×10^{0}	4.07×10^{0}	1.15×10^{0}	2.92×10^{1}	4.26×10^{0}
4.50×10^{1}	1.01×10^{0}	1.97×10^{0}	2.08×10^{0}	3.60×10^{0}	1.15×10^{0}	3.36×10^{1}	4.41×10^{0}
5.00×10^{1}	8.89×10^{-1}	1.78×10^{0}	1.82×10^{0}	3.22×10^{0}	1.14×10^{0}	3.80×10^{1}	4.55×10^{0}
6.00×10^{1}	7.05×10^{-1}	1.49×10^{0}	1.44×10^{0}	2.66×10^{0}	1.14×10^{0}	4.68×10^{1}	4.78×10^{0}
7.00×10^{1}	5.75×10^{-1}	1.28×10^{0}	1.17×10^{0}	2.27×10^{0}	1.13×10^{0}	5.57×10^{1}	4.98×10^{0}
8.00×10^{1}	4.77×10^{-1}	1.12×10^{0}	9.69×10^{-1}	1.97×10^{0}	1.13×10^{0}	6.45×10^{1}	5.15×10^{0}
9.00×10^{1}	4.03×10^{-1}	9.92×10^{-1}	8.15×10^{-1}	1.74×10^{0}	1.13×10^{0}	7.32×10^{1}	5.31×10^{0}
1.00×10^{2}	3.47×10^{-1}	8.90×10^{-1}	7.00×10^{-1}	1.56×10^{0}	1.13×10^{0}	8.19×10^{1}	5.48×10^{0}

IV. CONCLUSIONS

The authors have made a special effort to use the latest experimental data available at the time of this compilation. For some of the blast parameters there was little or no data near the surface of the charge. In some instances the curves were extrapolated or computer code calculations were used to guide the general shape of the blast parameter versus scaled distance.

With the publication of functional equations, tables, and plots in both Metric and English units for spherical TNT free-air bursts and hemispherical TNT surface bursts all in the same report, it should make it easy for the user to predict the blast parameters to be expected from any selected explosive yields.

The TNT surface burst data may be used to predict the blast parameters from nuclear surface bursts beyond a scaled distance of 0.79 $m/kg^{1/3}$ (2 $ft/lbm^{1/3}$) if it is assumed that fifty percent of the nuclear energy goes into producing blast parameters. That means a 1 Kt nuclear weapon would be equivalent to 0.5 Kt TNT high explosive yield.

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APPENDIX A

EQUATIONS AND CURVES FOR BLAST PARAMETERS FROM A SPHERICAL TNT FREE-AIR BURST PRESENTED IN METRIC UNITS AND ENGLISH UNITS.

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Functions to represent the airblast parameters versus distance in metres for a one kilogram TNT spherical free-air burst are presented in the following equations. The values in parentheses convert the equations to English units. Substituting the parenthesized values for the constants K_o and C_o, convert the equations to provide the free airblast parameters for a one pound TNT spherical charge versus distance in feet.

In general,

T = common logarithm of the distance in metres

$U = K_o + K_1 T$

Y = common logarithm of the airblast parameter in metric units

$Y = C_o + C_1 U + \ldots C_N U^N$

1. Incident pressure

Range of applicability: 0.0531 - 40.0 metres (0.134 - 100.0 feet)

(-0.756579301809)

$U = -0.214362789151 + 1.35034249993T$

(1.77284970457)

$$Y = 2.611368669 - 1.69012801396U + 0.00804973591951U^2 + 0.336743114941U^3 - 0.00516226351334U^4 - 0.0809228619888U^5 - 0.00478507266747U^6 + 0.00793030472242U^7 + 0.0007684469735U^8$$

2. Incident Impulse

Two functions required

Function I

Range of applicability: 0.0531 - 0.792 metres (0.134 - 2.00 feet)

(1.04504877747)

$U = 2.34723921354 + 3.24299066475T$

(1.43534136453)

$$Y = 2.38830516757 - 0.443749377691U + 0.168825414684U^2 + 0.0348138030308U^3 - 0.010435192824U^4$$

Function II

Range of applicability: (2.00 - 100.0 feet)
0.792 - 40.0 metres

$$U = -1.75305660315 + 2.30629231803T \quad (-2.67912519532)$$

$$\begin{aligned} Y = {} & 1.55197227115 - 0.40463292088U \quad (0.599008468099) \\ & -0.0142721946082U^2 + 0.00912366316617U^3 \\ & -0.0006750681404U^4 - 0.00800863718901U^5 \\ & +0.00314819515931U^6 + 0.00152044783382U^7 \\ & -0.0007470265899U^8 \end{aligned}$$

3. Reflected Pressure

Range of applicability: (0.134 - 100.0 feet)
0.0531 - 40.0 metres

$$U = -0.214362789151 + 1.35034249993T \quad (-0.756579301809)$$

$$\begin{aligned} Y = {} & 3.22958031387 - 2.21400538997U \quad (2.39106134946) \\ & +0.35119031446U^2 + 0.657599992109U^3 \\ & +0.0141818951887U^4 - 0.243076636231U^5 \\ & -0.0158699803158U^6 + 0.0492741184234U^7 \\ & +0.00227639644004U^8 - 0.00397126276058U^9 \end{aligned}$$

4. Reflected Impulse

Range of applicability: (0.134 - 100.0 feet)
0.0531 - 40.0 metres

$$U = -0.204004553231 + 1.37882996018T \quad (-0.757659920369)$$

$$\begin{aligned} Y = {} & 2.55875660396 - 0.903118886091U \quad (1.60579280091) \\ & +0.101771877942U^2 - 0.0242139751146U^3 \end{aligned}$$

5. Shock Front Velocity

Range of applicability: (0.134 - 100.0 feet) 0.0531 - 40.0 metres

$$U = -0.214362789151 + 1.35034249993T \quad (-0.756579301809)$$

$$\begin{aligned} Y = &-0.144615443471 - 0.650507560471U \quad (0.371369593444)\\ &+0.291320654009U^2 + 0.307916322787U^3\\ &-0.183361123489U^4 - 0.197740454538U^5\\ &+0.0909119559768U^6 + 0.0898926178054U^7\\ &-0.0287370990248U^8 - 0.0248730221702U^9\\ &+0.00496311705671U^{10} + 0.00372242076361U^{11}\\ &-0.0003533736952U^{12} - 0.0002292913709U^{13} \end{aligned}$$

6. Arrival Time

Range of applicability: (0.134 - 100.0 feet) 0.0531 - 40.0 metres

$$U = -0.253273111999 + 1.37407043777T \quad (-0.80501734056)$$

$$\begin{aligned} Y = &\ 0.0720707787637 + 1.36456871214U \quad (-0.0423733936826)\\ &-0.0570035692784U^2 - 0.182832224796U^3\\ &+0.0118851436014U^4 + 0.0432648687627U^5\\ &-0.0007997367834U^6 - 0.00436073555033U^7 \end{aligned}$$

7. Positive phase duration

Three functions required

Function I

Range of applicability: (0.370 - 2.24 feet) 0.147 - 0.888 metres

$$U = 2.26367268496 + 5.11588554305T \quad (0.209440059933)$$

(-0.801052722864)

$Y = -0.686608550419 + 0.164953518069U$

$+0.127788499497U^2 + 0.00291430135946U^3$

$+0.00187957449227U^4 + 0.0173413962543U^5$

$+0.00269739758043U^6 - 0.00361976502798U^7$

$-0.00100926577934U^8$

Function II

(2.24 - 5.75 feet)

Range of applicability: 0.888 - 2.28 metres

(-5.06778493835)

$U = -1.33361206714 + 9.2996288611T$

(0.115874238335)

$Y = 0.23031841078 - 0.0297944268969U$

$+0.0306329542941U^2 + 0.0183405574074U^3$

$-0.0173964666286U^4 - 0.00106321963576U^5$

$+0.0056206003128U^6 + 0.0001618217499U^7$

$-0.0006860188944U^8$

Function III

(5.75 - 100.0 feet)

Range of applicability: 2.28 - 40.0 metres

(-4.39590184126)

$U = -3.13005805346 + 3.1524725364T$

(0.50659210403)

$Y = 0.621036276475 + 0.0967031995552U$

$-0.00801302059667U^2 + 0.00482705779732U^3$

$+0.00187587272287U^4 - 0.00246738509321U^5$

$-0.000841116668U^6 + 0.0006193291052U^7$

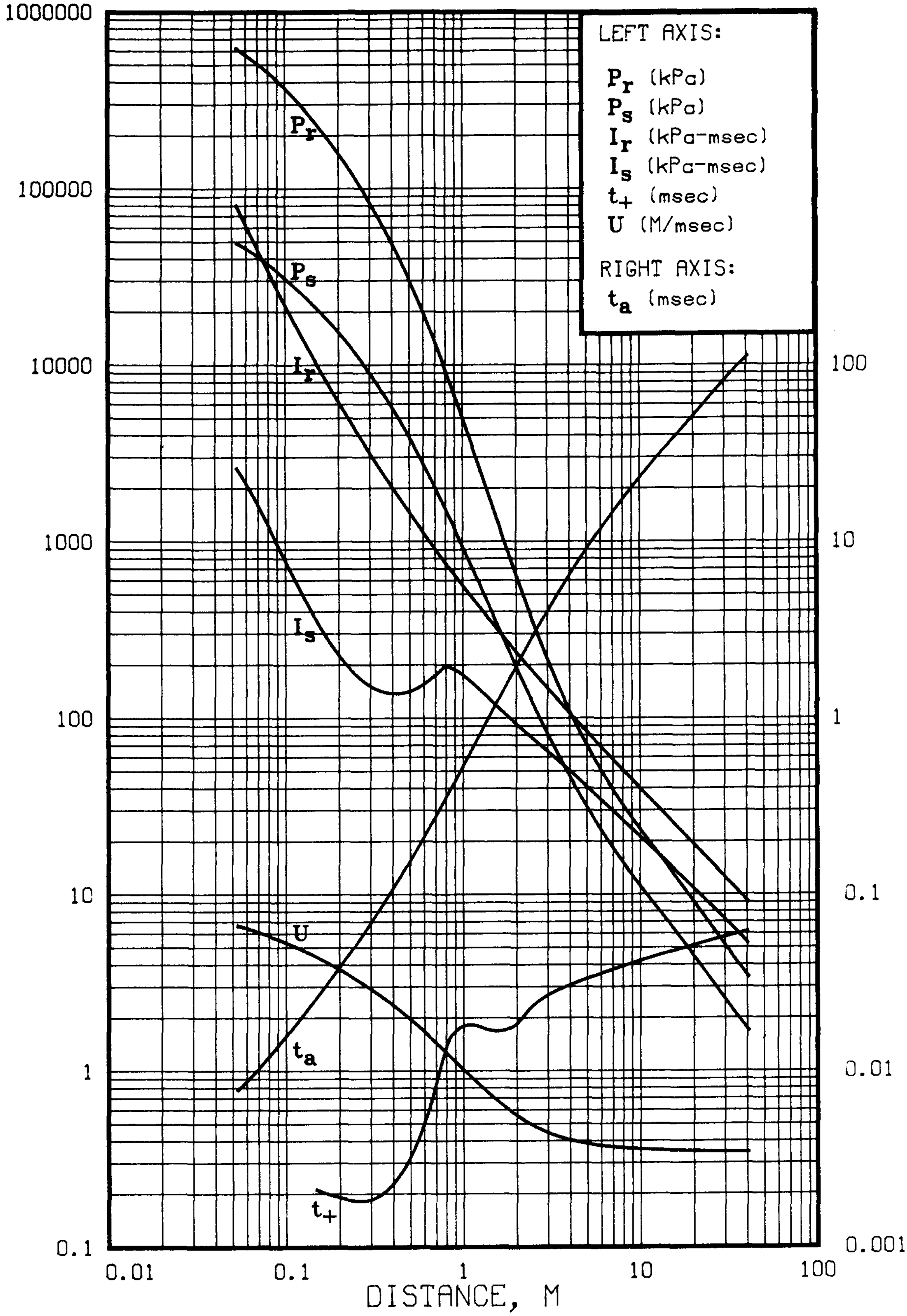

Figure A-1. Airblast Parameters versus Distance for a One Kilogram TNT Spherical Air Burst.

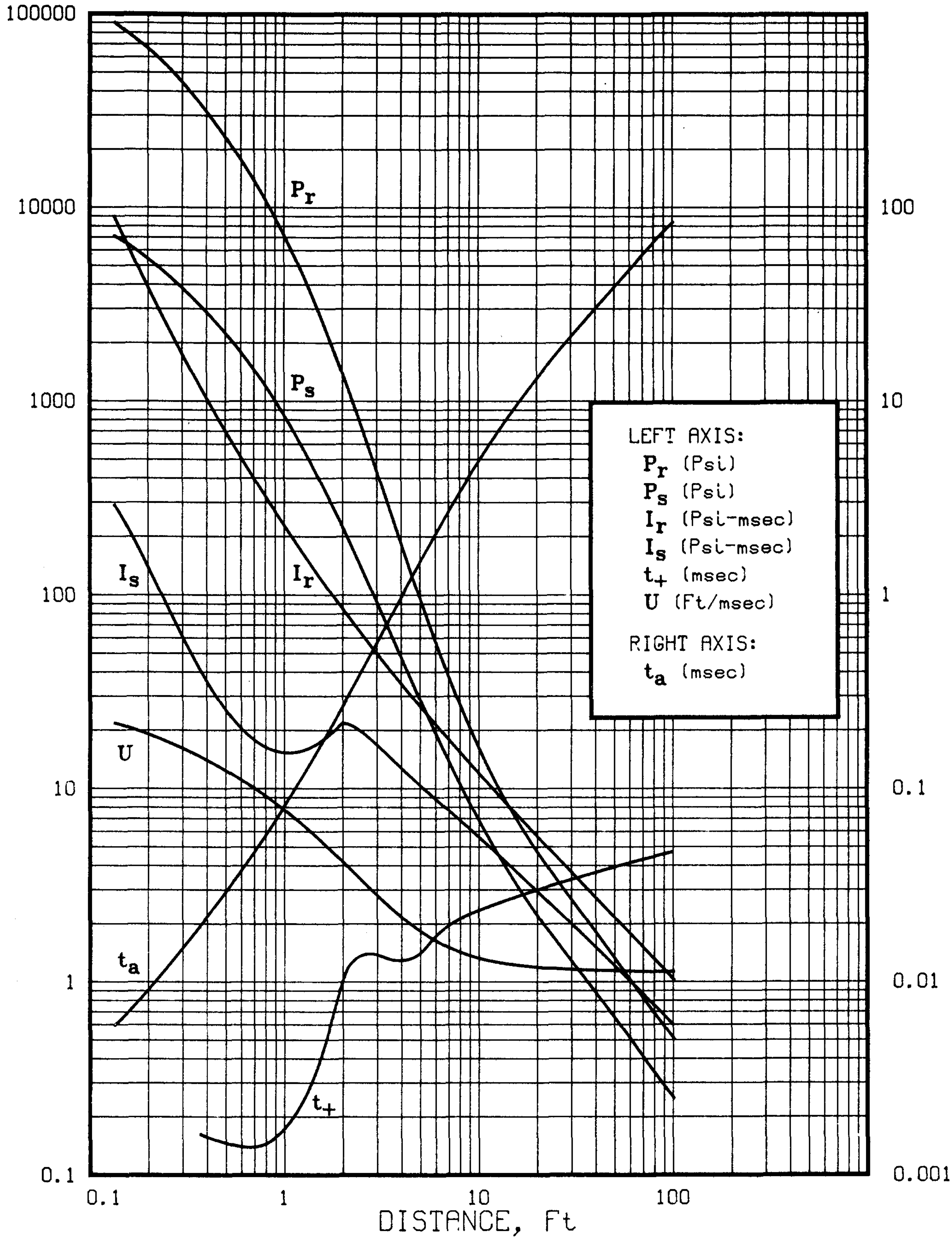

Figure A-2. Airblast Parameters versus Distance for a One Pound Mass TNT Spherical Air Burst.

APPENDIX B

EQUATIONS AND CURVES FOR BLAST PARAMETERS FROM A HEMISPHERICAL TNT SURFACE BURST PRESENTED IN METRIC UNITS AND ENGLISH UNITS.

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Functions to represent the airblast parameters versus distance in metres for a one kilogram TNT hemispherical surface burst are presented in the following equations. The values in parentheses convert the equations to English units. Substituting the parenthesized values for the constants K_o and C_o, convert the equations to provide the surface burst parameters for a one pound TNT hemispherical charge versus distance in feet.

In general,

T = common logarithm of the distance in metres (feet when ( ) values used.)

$U = K_o + K_1 T$

Y = common logarithm of the airblast parameter in metric units

$Y = C_o + C_1 U + \ldots C_N U^N$

1. Incident pressure

Range of applicability: 0.0674 - 40.0 metres (0.170 - 100.0 feet)

$$U = -0.214362789151\ (-0.756579301809) + 1.35034249993T$$

$$\begin{aligned} Y = {} & 2.78076916577\ (1.9422502013) - 1.6958988741U \\ & -0.154159376846U^2 + 0.514060730593U^3 \\ & +0.0988534365274U^4 - 0.293912623038U^5 \\ & -0.0268112345019U^6 + 0.109097496421U^7 \\ & +0.00162846756311U^8 - 0.0214631030242U^9 \\ & +0.0001456723382U^{10} + 0.00167847752266U^{11} \end{aligned}$$

2. Incident impulse

Two functions required

Function I

Range of applicability: 0.0674 - 0.955 metres (0.170 - 2.41 feet)

$$U = 2.06761908721\ (0.832468843425) + 3.0760329666T$$

$$\begin{aligned} Y = {} & 2.52455620925\ (1.57159240621) - 0.502992763686U \\ & +0.171335645235U^2 + 0.0450176963051U^3 \\ & -0.0118964626402U^4 \end{aligned}$$

Function II

$$\text{Range of applicability: } \begin{array}{l} (2.41 - 100.0 \text{ feet}) \\ 0.955 - 40.0 \text{ metres} \end{array}$$

$$\begin{array}{l} (-2.91358616806) \\ U = -1.94708846747 + 2.40697745406T \end{array}$$

$$\begin{array}{l} (0.719852655584) \\ Y = 1.67281645863 - 0.384519026965U \\ \quad -0.0260816706301U^2 + 0.00595798753822U^3 \\ \quad +0.014544526107U^4 - 0.00663289334734U^5 \\ \quad -0.00284189327204U^6 + 0.0013644816227U^7 \end{array}$$

3. Reflected pressure

$$\text{Range of applicability: } \begin{array}{l} (0.170 - 100.0 \text{ feet}) \\ 0.0674 - 40.0 \text{ metres} \end{array}$$

$$\begin{array}{l} (-0.789312405513) \\ U = -0.240657322658 + 1.36637719229T \end{array}$$

$$\begin{array}{l} (2.56431321138) \\ Y = 3.40283217581 - 2.21030870597U \\ \quad -0.218536586295U^2 + 0.895319589372U^3 \\ \quad +0.24989009775U^4 - 0.569249436807U^5 \\ \quad -0.11791682383U^6 + 0.224131161411U^7 \\ \quad +0.0245620259375U^8 - 0.0455116002694U^9 \\ \quad -0.00190930738887U^{10} + 0.00361471193389U^{11} \end{array}$$

4. Reflected impulse

$$\text{Range of applicability} = \begin{array}{l} (0.170 - 100.0 \text{ feet}) \\ 0.0674 - 40.0 \text{ metres} \end{array}$$

$$\begin{array}{l} (-0.781951689212) \\ U = -0.246208804814 + 1.33422049854T \end{array}$$

$$\begin{array}{l} (1.75291677799) \\ Y = 2.70588058103 - 0.949516092853U \\ \quad +0.112136118689U^2 - 0.0250659183287U^3 \end{array}$$

5. Shock front velocity

$$\text{Range of applicability: } \begin{array}{l} (0.170 - 100.0 \text{ feet}) \\ 0.0674 - 40.0 \text{ metres} \end{array}$$

$$\begin{array}{l} (-0.755684472698) \\ U = -0.202425716178 + 1.37784223635T \end{array}$$

$$(0.449774310005)$$

$$\begin{aligned}Y = &-0.06621072854 - 0.698029762594U \\ &+0.158916781906U^2 + 0.443812098136U^3 \\ &-0.113402023921U^4 - 0.369887075049U^5 \\ &+0.129230567449U^6 + 0.19857981197U^7 \\ &-0.0867636217397U^8 - 0.0620391900135U^9 \\ &+0.0307482926566U^{10} + 0.0102657234407U^{11} \\ &-0.0054653325077 2U^{12} - 0.000693180974U^{13} \\ &+0.0003847494916U^{14}\end{aligned}$$

6. Arrival time

Range of applicability: (0.170 - 100.0 feet) 0.0674 - 40.0 metres

$$(-0.755684472698)$$

$$U = -0.202425716178 + 1.37784223635T$$

$$(-0.173607601251)$$

$$\begin{aligned}Y = &-0.0591634288046 + 1.35706496258U \\ &+0.052492798645U^2 - 0.196563954086U^3 \\ &-0.0601770052288U^4 + 0.0696360270891U^5 \\ &+0.0215297490092U^6 - 0.0161658930785U^7 \\ &-0.00232531970294U^8 + 0.00147752067524U^9\end{aligned}$$

7. Positive phase duration

Three functions required

Function I

Range of applicability: (0.450 - 2.54 feet) 0.178 - 1.01 metres

$$(-0.1790217052)$$

$$U = 1.92946154068 + 5.25099193925T$$

$$(-0.728671776005)$$

$$\begin{aligned}Y = &-0.614227603559 + 0.130143717675U \\ &+0.134872511954U^2 + 0.0391574276906U^3 \\ &-0.00475933664702U^4 - 0.00428144598008U^5\end{aligned}$$

Function II

(2.54 - 7.00 feet)
Range of applicability: 1.01 - 2.78 metres

(-5.85909812338)
$$U = -2.12492525216 + 9.2996288611T$$

(0.20096507334)
$$Y = 0.315409245784 - 0.0297944268976U + 0.030632954288U^2 + 0.0183405574086U^3 - 0.0173964666211U^4 - 0.00106321963633U^5 + 0.00562060030977U^6 + 0.0001618217499U^7 - 0.0006860188944U^8$$

Function III

(7.00 - 100.0 feet)
Range of applicability = 2.78 - 40.0 metres

(-4.92699491141)
$$U = -3.53626218091 + 3.46349745571T$$

(0.572462469964)
$$Y = 0.686906642409 + 0.0933035304009U - 0.0005849420883U^2 - 0.0022688499501 3U^3 - 0.00295908591505U^4 + 0.00148029868929U^5$$

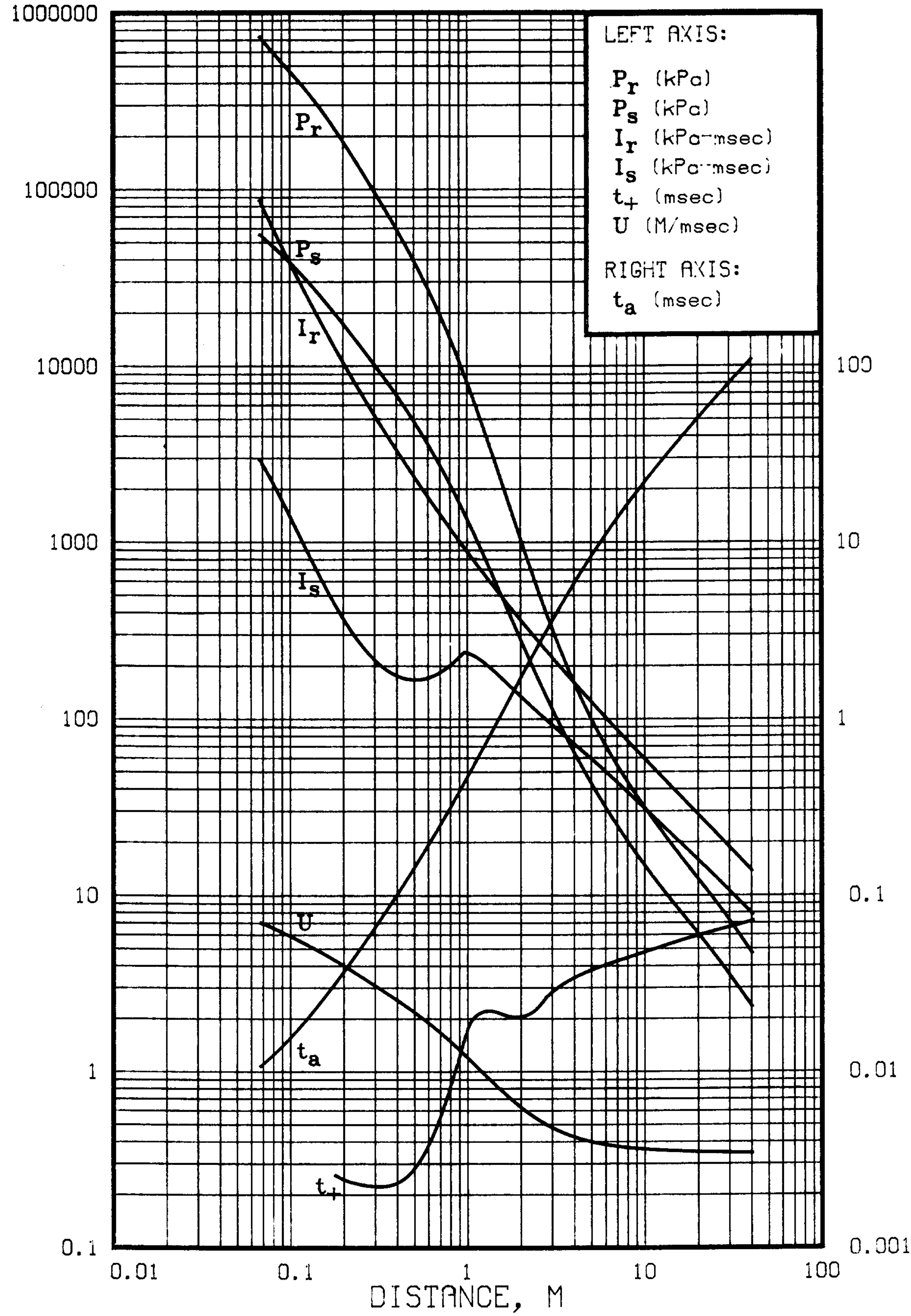

Figure B-1. Airblast Parameters versus Distance for a One Kilogram TNT Hemispherical Surface Burst.

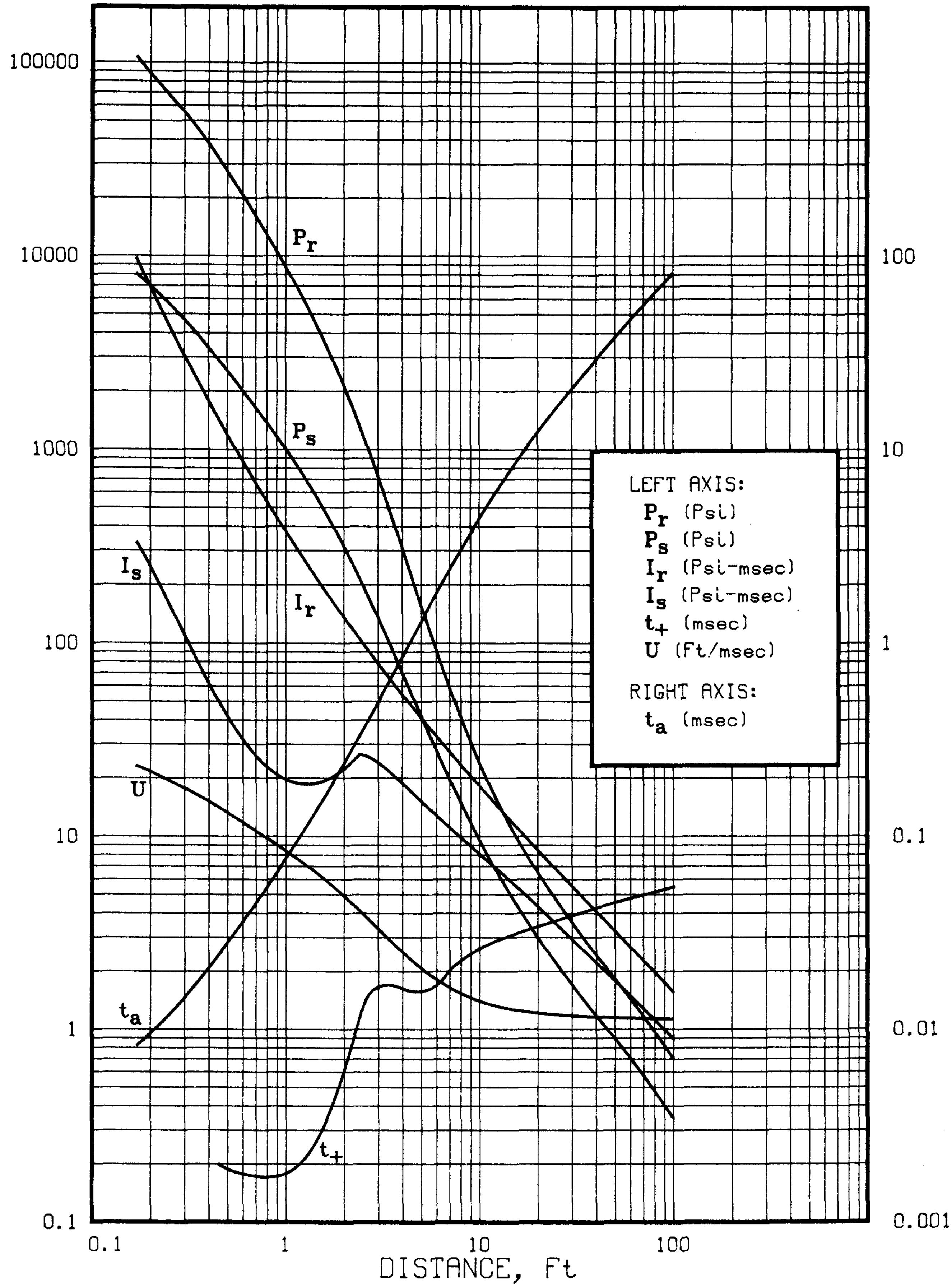

Figure B-2. Airblast Parameters versus Distance for a One Pound Mass TNT Hemispherical Ground Burst.

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REPLY TO
ATTENTION OF

SLCBR-TB-B (70)

October 10, 1991

MEMORANDUM FOR Chairman, Department of Defense Explosives Board,
ATTN: Dr. Jerry Ward, 2461 Eisenhower Avenue,
Alexandria, VA 22331-0600

SUBJECT: Supporting Data for BRL-TR-2555

1. This memorandum is in response to your request for data on 30 September 1991 supporting BRL-TR-2555, "Airblast Parameters from TNT Spherical Air Burst and Hemispherical Surface Burst," Charles N. Kingery and Gerald Bulmash, April 1984. The research and analysis that is reported in TR-2555 was funded entirely by DDESB. The work was performed at BRL from June 1981 to June 1983. The impetus for this work was revision, by the DDESB, of the tri-service manual, "Structures to Resist the Effects of Accidental Explosions," TM5-1300, June 1969.

2. You specifically requested the data that was used to generate the functions and plots in TR-2555 in order that other researchers employing this data could develop confidence intervals appropriate to their applications. You also wanted a copy of this data to insure that it is not lost to DDESB since this report is frequently used within the blast community and for structural design.

3. Mr. Bulmash has examined his notes from 1981 - 1983 and has reproduced a copy of the pertinent information which is enclosed. All of this information was unclassified when TR-2555 was published in 1984 and remains unclassified. If clarification or more data is required, please contact Mr. Bulmash at 301 278-6020 and he will attempt to provide the additional information.

FOR THE DIRECTOR:

Encl

ANDREW MARK
Chief, Blast Dynamics Branch

DD ESB Analysis – Part I

NOTEBOOK NO. TBD 201

ISSUED TO GERALD BULMASH

ON 23 MARCH **19**82

DEPARTMENT TBD

RETURNED **19**

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Project No.________

TITLE DDESB ANALYSIS Book No. 1

From Page No.__ Summary of DDESB Analysis from 6/8/81 – 4/6/82

I began my professional career at BRL on 6/8/81 and performed an extensive data analysis for revision of the air blast parametrization curves incorporated in the Dept. of Defense Explosive Safety Board Tri-Service Manual, "Structu[res] to Resist the Effects of Accidental Explosions" (TM 5-1300), Ju[ne]. I was issued this lab notebook 3/23/82. Therefore, I am including this summary of work performed on this project during the 9 month interim before the notebook was issued.

① Data reduction of BRL report #1950, "Air Blast Data From Height-of-Burst Studies in Canada, Volume I: HOB 5.4 to 71.9 feet", by Reisler, Pettit, and Kennedy, published Dec. 1976. and data reduction of BRL report # 1990, "Air Blast Data Fr[om] Height-of-Burst Studies in Canada, Volume II: HOB 45.4 to 144.5 feet.", by Reisler, Pettit, and Kennedy, May 1977.

The air blast parameters in TM 5-1300, figure 4-5 are for a one pound spherical TNT explosion in free air at sea level. (See attachment #1 – opposite). To include raw data from BRL #1950 + #1990 in the revision of the TM 5-13[00] curves it was necessary to analyze #1950 + 1990 to determine which data represented free field data not in the Mach reflection region, scale the data for atmospheric conditions (Canadian tests performed at high altitude), scale the 1000 LB TNT data to 1 LB TNT, generate graphs comparing the data with TM 5-1300 and other sources.

A. Determination of appropriate data from #1950 and #1990. I analyzed the raw data and incident pressure and impulse curves for all experimental shots reported in these two reports.

#1950 Shots 1 thru 10 conducted 9/16/69 – 11/18/69
#1990 Shots 17 thru 24 conducted 6/23/75 – 8/18/75

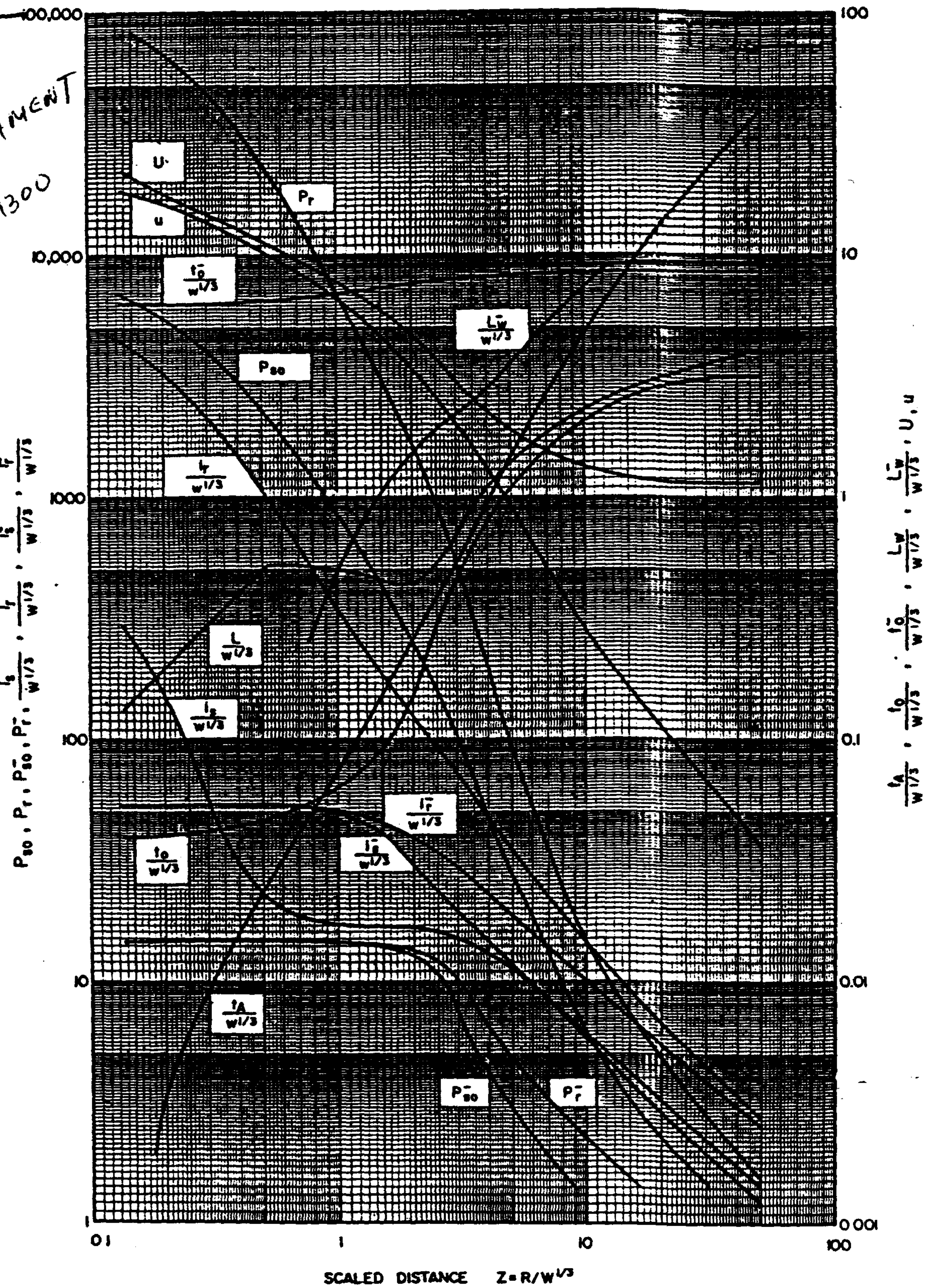
Attachments #2, #3, and #4 (next page) are from #1950. They display incident pressure and impulse records and a ground station record for shot 3, HOB 36.7 ft.

Work continued on page 2. 4/8/82 Gerald Bulmash

To Page No.

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

ATTACHMENT #1 TM5-1300



P_{so} = Peak Positive Incident Pressure, psi
P_{so}^- = Peak Negative Incident Pressure, psi
P_r = Peak Positive Normal Reflected Pressure, psi
P_r^- = Peak Negative Normal Reflected Pressure, psi
$i_s/W^{1/3}$ = Scaled Unit Positive Incident Impulse, psi-ms/lb$^{1/3}$
$i_s^-/W^{1/3}$ = Scaled Unit Negative Incident Impulse, psi-ms/lb$^{1/3}$
$i_r/W^{1/3}$ = Scaled Unit Positive Normal Reflected Impulse, psi-ms/lb$^{1/3}$
$i_r^-/W^{1/3}$ = Scaled Unit Negative Normal Reflected Impulse, psi-ms/lb$^{1/3}$
$t_A/W^{1/3}$ = Scaled Time of Arrival of Blast Wave, ms/lb$^{1/3}$
$t_o/W^{1/3}$ = Scaled Positive Duration of Positive Phase, ms/lb$^{1/3}$
$t_o^-/W^{1/3}$ = Scaled Negative Duration of Positive Phase, ms/lb$^{1/3}$
$L_w/W^{1/3}$ = Scaled Wave Length of Positive Phase, ft/lb$^{1/3}$
$L_w^-/W^{1/3}$ = Scaled Wave Length of Negative Phase, ft/lb$^{1/3}$
U = Shock Front Velocity, ft/ms
u = Particle Velocity, ft/ms
W = Charge Weight, lbs
R = Radial Distance from Charge, ft
Z = Scaled Distance, ft/lb$^{1/3}$

Figure 4-5. Shock-wave parameters for spherical TNT explosion in free air at sea level.

Attachment #2 shows the incident pressure and impulse record for a pressure transducer located 60 feet horizontally from ground zero and 40 feet above the ground. At this station the shock wave has decayed to ambient pressure before the arrival of the shock wave being reflected from the ground. Therefore the impulse record represents incident impulse. The data from this station can be validly included in determination of free air TNT incident impulse and pressure curves.

Attachment #3 shows that at a gauge location 60 feet horizontally from ground zero and 10 feet above ground the reflected wave arrives before the incident wave decays to zero. The pressure record peak does not represent incident pressure and the peak impulse does not represent incident impulse

Attachment #4 displays pressure and impulse records on the ground 60 feet horizontally from ground zero. The record does not show a reflection of course but is inappropriate for inclusion in a set of free air curves because it represents neither incident pressure nor normally reflected pressure. Stations located horizontally at 0 feet from ground zero give true normally reflected pressure records and are included in determination of reflected pressure and reflected impulse curves for free air TNT

B. Scaling for atmospheric conditions and charge weight.
Data reported in #1950 and #1990 was obtained by experimental test programs performed by BRL in conjunction with the Defence Research Establishment Suffield (DRES) near Medicine Hat, Alberta, Canada. This is high prairie country and made it necessary to correct atmospheric pressure due to altitude.

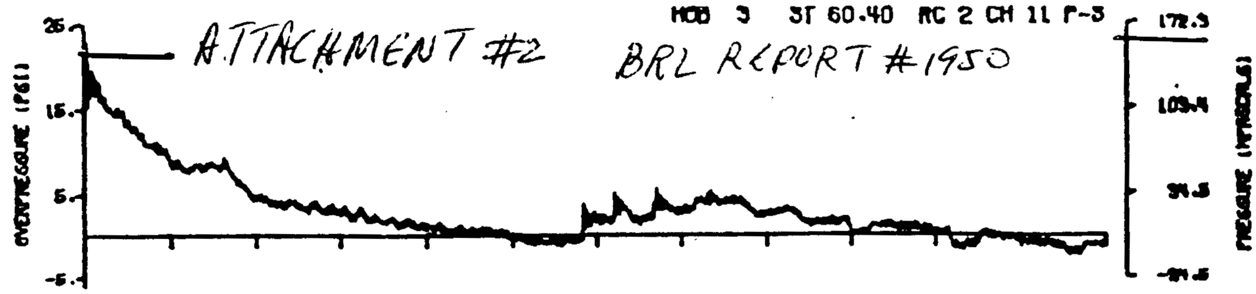
The experimental program reported in #1950 used 1000 LB spherical TNT charges; that reported in #1990 used 1040 LB spherical TNT charges. I scaled these to one LB standard conditions at sea level for inclusion in the blast parameters revision.

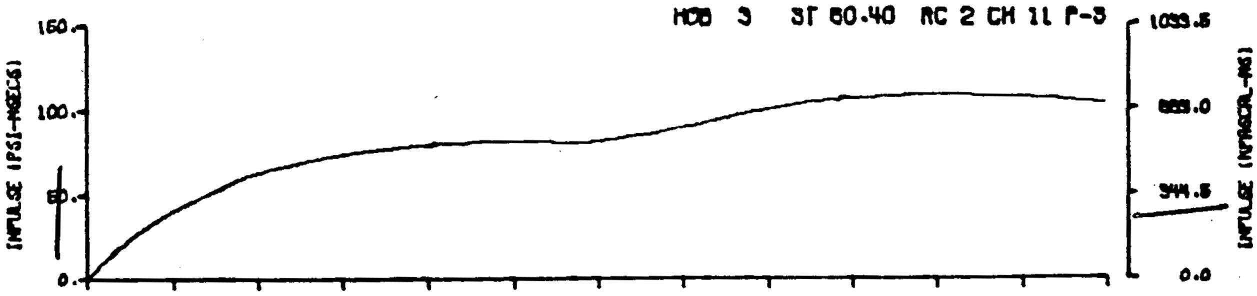
Since the energy of an explosive is proportional to its mass, and the dispersion of its energy as the blast wave moves outward radially from a free air blast, is proportional

Work continued. 4/8/82 Gerald Bulmash

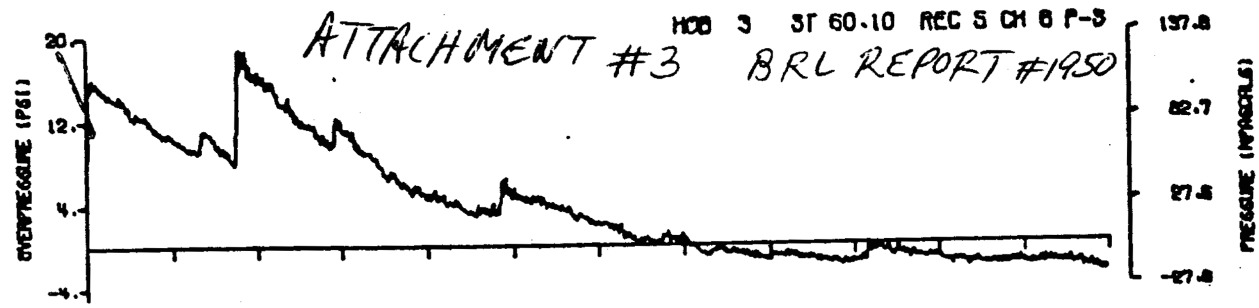
Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

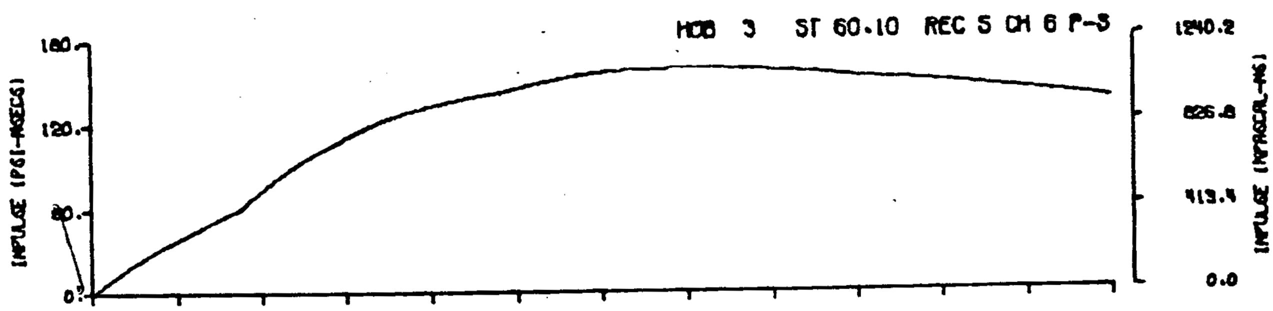
ATTACHMENT #2 BRL REPORT #1950



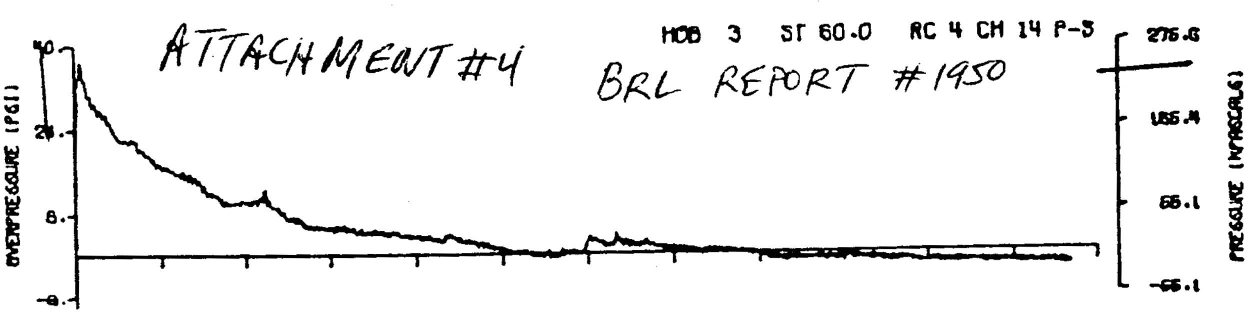


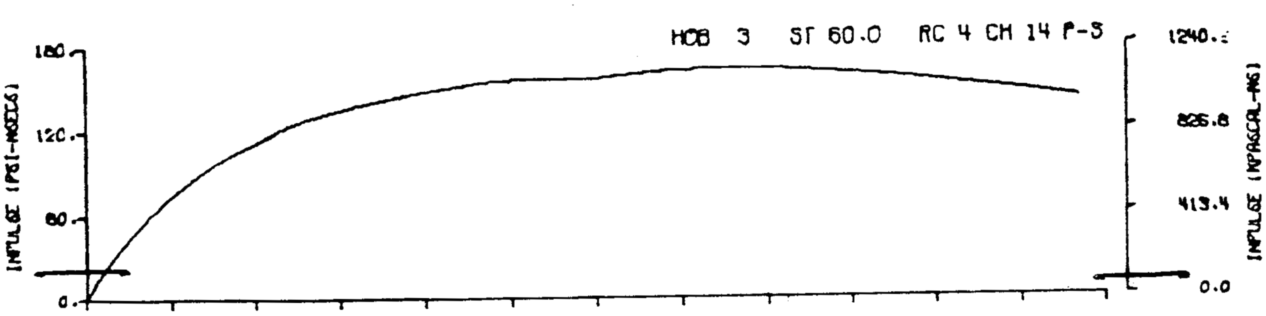
ATTACHMENT #3 BRL REPORT #1950





ATTACHMENT #4 BRL REPORT #1950





From Page No. 2 to the ~~inverse of the~~ cube ~~root~~ of the distance, it was appropriate to use Hopkinson's Scaling Laws. I used AMC Pamphlet AMCP 706-181, "Engineering Design Handbook, Explosions in Air, Part One", July, 1974, as a reference for the scaling laws.

Scaling to one LB standard conditions

Pressure at sea level = $P S_p$ where $S_p = \frac{P_o}{P_a}$ $\quad P_{SL} = P \frac{P_o}{P_a}$

P = measured pressure
P_o = standard sea level pressure = 14.7 psi
P_a = ambient pressure.

Slant Range at sea level = $D S_D$ $\quad S_D = \left(\frac{P_a}{P_o}\right)^{\frac{1}{3}} \left(\frac{1}{W}\right)^{\frac{1}{3}}$

W = charge weight $\quad D_{SL} = D\left(\frac{P_a}{P_o}\right)^{\frac{1}{3}} \left(\frac{1}{W}\right)^{\frac{1}{3}}$

Duration at sea level = $t S_t$ $\quad S_t = \left(\frac{T_a}{T_o}\right)^{\frac{1}{2}} \left(\frac{P_a}{P_o}\right)^{\frac{1}{3}} \left(\frac{1}{W}\right)^{\frac{1}{3}}$

$$t_{S.L} = t\left(\frac{T_a}{T_o}\right)^{\frac{1}{2}} \left(\frac{P_a}{P_o}\right)^{\frac{1}{3}} \left(\frac{1}{W}\right)^{\frac{1}{3}}$$

T_0 = standard temperature = 518.4 ° Rankine.

Impulse at sea level = $I S_I$ $\quad S_I = \left(\frac{T_a}{T_o}\right)^{\frac{1}{2}} \left(\frac{P_o}{P_a}\right)^{\frac{2}{3}} \left(\frac{1}{W}\right)^{\frac{1}{3}}$

$$I_{S.L.} = I\left(\frac{T_a}{T_o}\right)^{\frac{1}{2}} \left(\frac{P_o}{P_a}\right)^{\frac{2}{3}} \left(\frac{1}{W}\right)^{\frac{1}{3}}$$

represents scaling for pressure and time.

C. Reduced data for inclusion in the revised air blast parameter curves.

Attachments #5A-5D (next two pages, both sides) are photocopies of the data reduction I performed on Shot 20, from

Work continued 4/8/82 Gerald Bulmash To Page No. 6

K-20 22 July 1975 Attachment #5A Dipole

HOB 120.6 ft.

Station Range (ft)	Station Height (ft)	Slant Range (ft)	Time of Arrival (msec)	Incident Overpressure (psi)	Positive Phase Duration (msec)
0	0	120.7	62.0	12.8	19.5
2-7	0	120.9	62.2	10.6	25.0
10	0 N	121.1	62.3	11.6	24.0
2-15	0	121.6	62.7	10.4	20.6
20	0	122.3	63.0	10.0	23.6
2-20	0	122.3	63.2	9.0	18.6
20	3	119.3	60.7	5.8	35.0
20	10	112.4	55.5	5.4	14.6
20	20	102.6	48.0	6.8	16.0
20	30	92.83	41.0	8.8	16.8
20	40	83.09	34.3	11.0	17.6
30	0	124.3	64.5	11.0	24.0
2-30	0	124.3	64.8	9.8	22.0
30	3	121.4	62.3	4.6	35.0
30	10	114.6	57.0	6.2	35.5
30	20	105.0	49.8	7.8	20.6
30	30	95.49	42.7	8.1	19.6
30	40	86.05	36.0	8.8	19.0
40	0	127.1	66.4	9.7	24.6
2-40	0	127.1	67.0	9.2	24.6
40	3	124.3	64.7	4.5	25.4
40	10	117.7	59.0	4.8	36.0
40	20	108.3	52.0	5.8	19.0
40	30	99.08	45.2	7.8	20.0
40	40	90.02	38.7	8.6	18.0
50	0 N	130.6	70.0	9.0	25.0
60	0	134.7	72.2	9.2	24.4
2-60	0	134.7	72.8	8.6	25.0
60	3	132.1	70.5	4.1	26.0
2-60	3	132.1	70.7	4.5	26.0
60	10	125.9	65.5	4.5	34.8
60	20	117.2	58.7	5.2	19.5
60	30	108.7	52.4	5.8	17.0
60	40	100.5	46.4	7.4	19.8

West ~~-~~ * Gr...

\+ Reflection before incident wave decays to zero

ATTACHMENT #5B

Scaled to 1 LB blast under standard conditions

Overpressure Impulse		Slant Range	TOA	Incident Overpres.	Pos. Phase Duration	Incident wave Impulse
(psi-msec)		(ft)	(m sec)	(psi)	(m sec)	(psi-msec)
96.5	0,23	11.59	6.04	13.89	1.90	10.19
113		11.61	6.06	11.50	2.44	11.93
103		11.63	6.07	12.59	2.34	10.88
73.5		11.67	6.11	11.28	2.01	7.76
125		11.74	6.14	10.85	2.30	13.20
57.0		11.74	6.16	9.77	1.81	6.02
101		11.45	5.91	6.29		
35.7	P1234	10.79	5.41	5.86	1.42	3.77
40.4	P1234	9.85	4.68	7.38	1.56	4.27
41.4	P1234	8.91	3.99	9.55	1.64	4.37
62.2	P1234	7.98	3.34	11.94	1.71	6.57
98.5		11.93	6.28	11.94	2.34	10.40
73.6		11.93	6.31	10.63	2.14	7.77
90.0		11.65	6.07	4.99		
88.5		11.00	5.55	6.73		
49.0	P1234	10.08	4.85	8.46	2.01	5.17
53.0	P1234	9.17	4.16	8.79	1.91	5.60
57.2	P1234	8.26	3.51	9.55	1.85	6.04
90.0		12.20	6.47	10.52	2.40	9.50
87.0		12.20	6.53	9.98	2.40	9.19
80.2		11.93	6.30	4.88		
73.2		11.30	5.75	5.21		
41.5	P1234	10.40	5.06	6.29	1.85	4.38
53.7	P1234	9.51	4.40	8.46	1.95	5.67
57.6	P1234	8.64	3.77	9.33	1.75	6.08
82.4		12.54	6.82	9.77	2.44	8.70
84.2		12.93	7.03	9.98	2.38	8.89
79.0		12.93	7.09	9.33	2.44	8.34
77.5		12.68	6.87	4.45		
82.5		12.68	6.89	4.88		
69.8		12.09	6.38	4.88		
40.8	P1234	11.25	5.72	5.64	1.90	4.31
42.0	P1234	10.44	5.10	6.29	1.66	4.44
51.4	P1234	9.65	4.52	8.03	1.93	5.43

ATTACHMENT #5C

Station Range (ft)	Station Height (ft)	Slant Range (ft)	Time of Arrival (msec)	Incident Overpressure (psi)	Positive Phase Durati.. (msec)
2-80	0	144.8	81.3		
90	0	150.5	85.1	7.9	24.0
2-90	0	150.5	85.1	7.4	23.0
90	3	148.1	83.8	3.7	31.4
90	10	142.6	79.0	3.7	
90	20	135.0	72.3	3.4	
90	30	127.7	67.2	4.0	32.0
90	40	120.8	61.4	5.2	32.0
2-100	0	156.7	90.9	6.8	19.2
110	0	163.3	94.7	6.6	24.3
2-110	0	163.3	96.0	6.6	23.7
2-120	0	170.2	102.0	6.8	26.0
2-130	0	177.3	107.5	5.5	25.6
2-140	0	184.8	113.3	4.5	21.1
150	0	192.5	119.0	5.2	28.2
2-150	0	192.5	119.7	4.6	21.8
150	3	190.6	117.1	2.3	38.4
150	10	186.4	113.9	2.2	37.1
150	20	180.6	108.8	2.6	42.9
150	30	175.3	104.3	2.4	
150	40	170.3	100.5	2.8	35.2
2-200	0	233.6	154.2	4.0	28.8
245	0	273.1	186.2	3.5	27.5
2-245	0	273.1	187.5	4.0	26.9
245	3	271.8	184.3	2.8	36.5
245	10	268.8	182.4	1.9	27.5
245	20	264.9	179.2	1.8	57.6
245	30	261.2	176.0	2.0	38.4
245	40	257.9	172.8	2.2	49.6
400	0	417.8	308.8	2.5	40.0
2-400	0	417.8	312.0	2.0	
600	0	612.0	475.2	1.6	40.0
814	6	823.5	644.8	1.2	43.2
1000	0A	1007	819.2	0.66	
1000	0B	1007	819.2	0.70	43.0

AIINCHAMEWI #5D

Scaled to 1 LB blast
under standard conditions

Overpressure Impulse (psi-msec)	Slant Range (ft)	TOA (msec)	Incident Overpres (psi)	For Phase Duration (msec)	Incident Wave Impulse (psi-msec)
74.5	14.45	8.29	8.57	2.34	7.87
90.0	14.45	8.29	8.03	2.24	9.50
75.0	14.22	8.16	4.01		
40.0	12.26	6.55	4.34	3.12	4.22
46.0	11.60	5.98	5.64	3.12	4.86
36.6	15.04	8.85	7.38	1.87	3.86
60.0	15.68	9.22	7.16	2.37	6.34
54.0	15.68	9.35	7.16	2.31	5.70
52.0	16.54	9.93	7.38	2.53	5.49
40.8	17.02	10.47	5.97	2.49	4.31
20.8					
56.0	18.48	11.59	5.64	2.75	5.91
33.0	18.48	11.66	4.99	2.12	3.48
56.5	18.30	11.41	2.50		
53.7	17.89	11.09	2.37		
54.8	17.34	10.60	2.82		
32.4	16.35	9.79	3.04	3.43	3.42
38.6	22.43	15.02	4.34	2.81	4.08
34.0	26.22	18.14	3.80	2.68	3.59
32.6	26.22	18.36	4.34	2.62	3.44
31.6					
35.4	25.80	17.77	2.06		
71.8	25.43	17.45	1.95		
36.0	25.08	17.14	2.17		
33.5	24.76	16.83	2.39		
26.5	40.11	30.08	2.71	3.90	2.80
15.8					
13.0					
4.4					

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From Page No. 3 report #1990. A similar data reduction was performed on all shots from reports #1950 and #1990.

D. Graph of Incident Pressure vs. Distance
Attachment #6 opposite shows 155 data points for incident pressure vs distance for reduced data obtained from #1950 and #1990. The smooth line to fit the data was arrived at by using a a Tektronix 4051 Computer and a statistical software package provided by Tektronix entitled, "Plot 50, Mathematics, Volume 2."

I used a cubic spline data fitting routine to generate a smooth curve to fit the data. A spline is a piecewise cubic polynomial fitted together so that the 1st and second derivatives are continuous. This piecing together allows the drawing of smooth curves for a large number of data points but does not provide a usable function for regenerating the curve independently of the 4051 computer.

Attachment #7 (next page) demonstrates the smooth cubic spline curve and the data spread for incident pressure. Comparison with TM5-1300 and other sources indicated that this data concurred with other sources. However, it also manifests the range and domain limitations of pressure transducer data obtained by #1950 and #1990. DDESB is interested in overpressure data from the charge surface outward to at least where the overpressure has decayed to 0.7 psi.

Similar statistical data fits were performed on the other blast parameters listed on attachment #5, ie, Time of arrival, Incident pressure, Duration, and Impulse

Gerald B almosh 4/9/82

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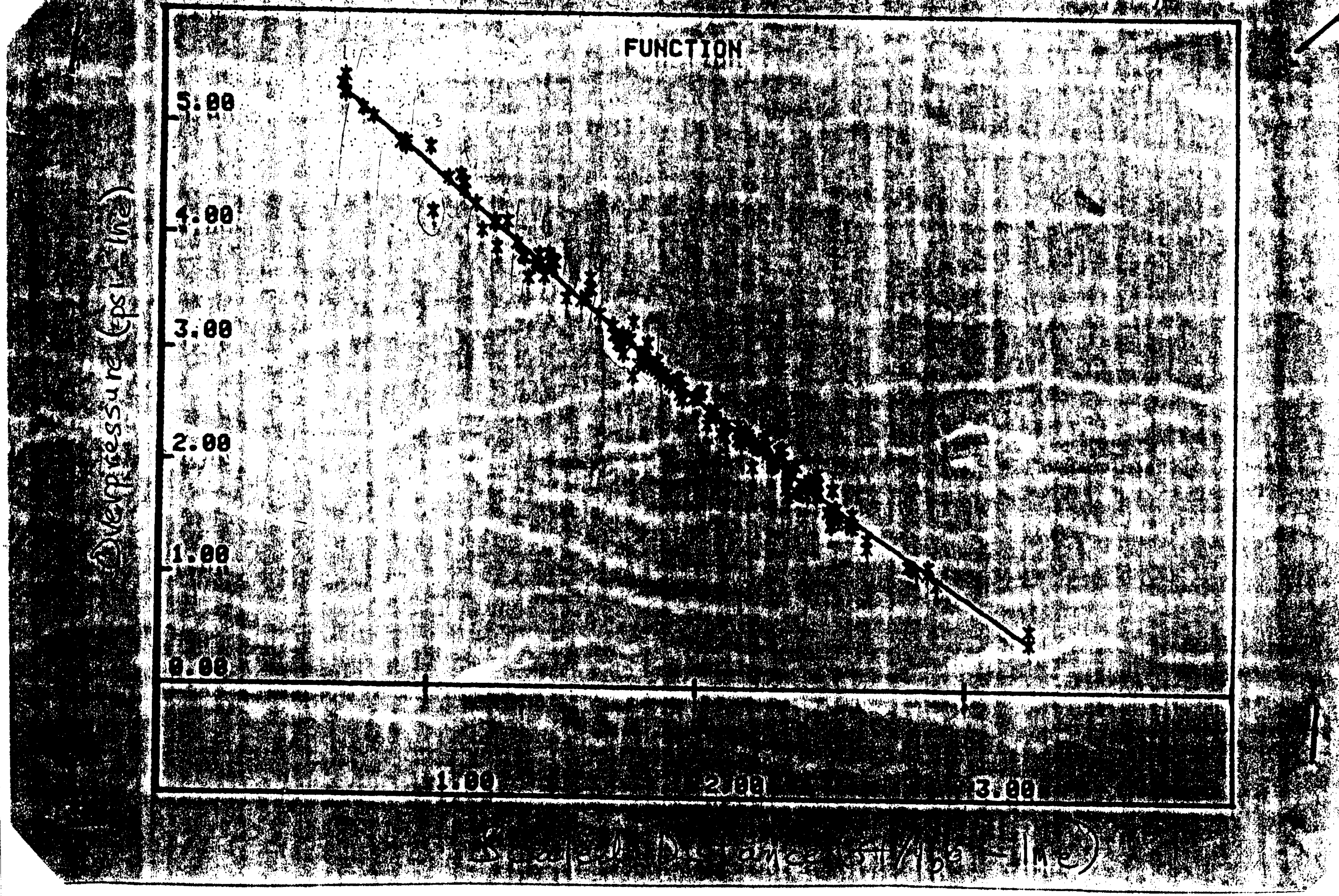
Attachment #6 Data Fitting - Cubic Spline S = 20 smoothing factor



Project No.
TITLE PDESB Analysis
Book No.

From Page No. ② Comparison of other sources of raw data and reduced data for inclusion in the revision of TM 5-1300 free air TNT curves.

A. Incident Pressure

1) BRL Reports # 1950 and # 1990. Comparison Range 230.4-1.63 psi
Values obtained by cubic spline smoothing

Distance (ft/lb$^{1/3}$)	Overpressure (psi)
1.82	230.4
2.01	186.8
2.22	152.9
2.72	101.5
3.32	67.4
4.48	36.2
6.05	19.7
9.02	9.02
12.18	5.21
16.44	3.16
20.09	2.27
24.53	1.63

2) Naval Surface Weapons Center / WOL / TR 75-116 curve
This is a composite curve based on 9 different sources of data prepared by NSWC. The curve lists pressure in bars vs distance in meter / Kilogram$^{1/3}$. Comparison Range 797.5 - 1.60 psi

1 bar = 14.5 psi $\quad \frac{3.2808 \text{ ft per m}}{(2.2046)^{1/3} \text{ lb/Kg}^{1/3}} = 2.5208$

Distance (ft/lb$^{1/3}$)	Overpressure (psi)
1.01	797.5
1.26	507.5
2.52	130.5
5.04	26.8
12.60	4.64
25.21	1.60
50.42	0.682

Work continued Gerald Bulmash 4/9/82

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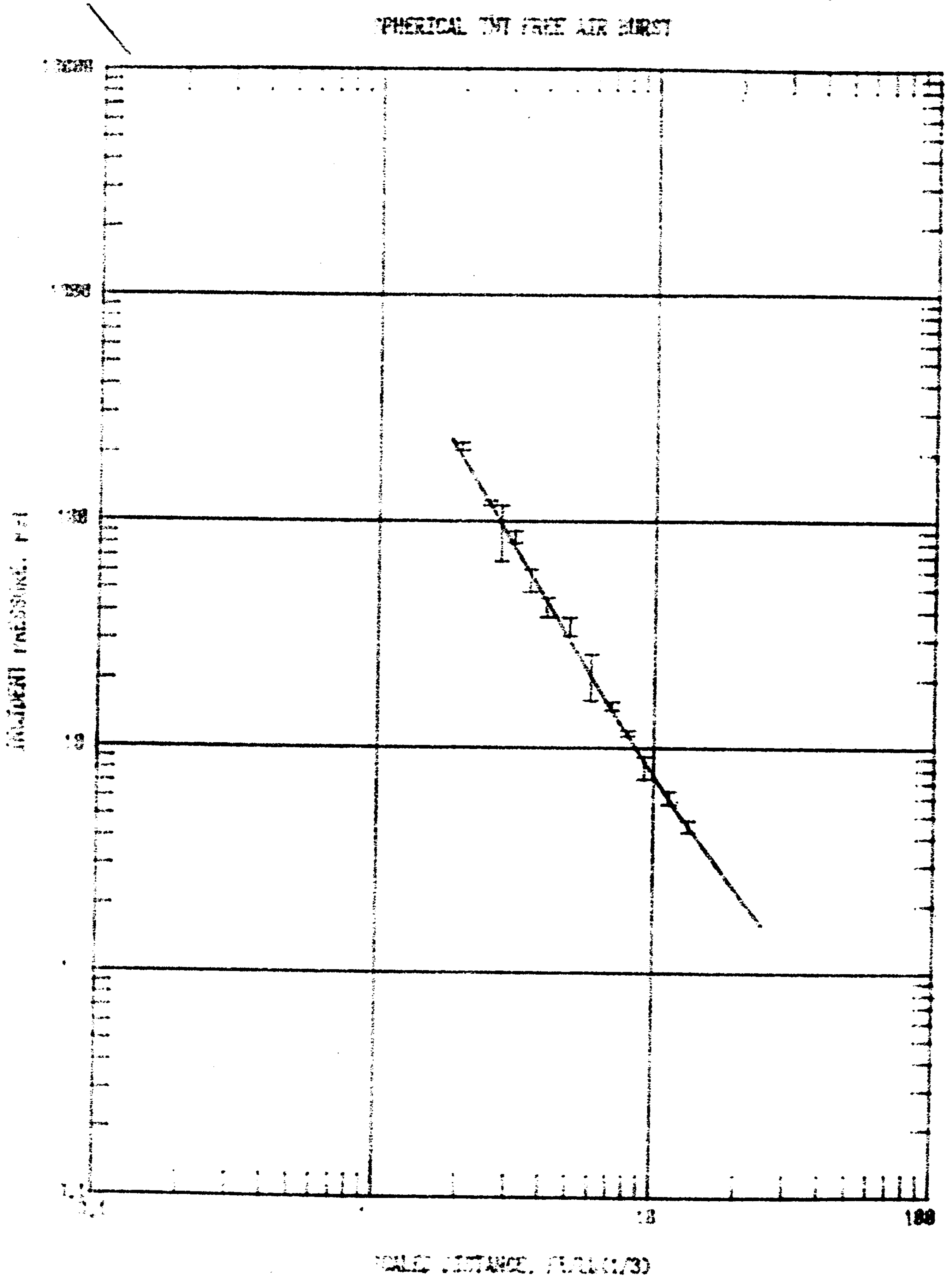
ATTACHMENT #7



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From Page No 7 3) BRL Report #1344, "Air Blast Parameters vs. Distance for Hemispherical TNT Surface Bursts", Kingery, 1966.

A hemispherical surface burst is twice as powerful as a free air burst of comparable charge weight if the ground is considered to be a perfect reflector.

Scaling for charge weight, $\frac{1}{W^{1/3}} = \frac{1}{2^{1/3}} = 0.7937$.

Allowing for some energy dissipation due to the ground being an imperfect reflector, ie, cratering and soft ground resulting in inelastic collisions with the shock front, I considered the free air effects of a hemispherical surface burst to be 1.8 as powerful as a comparable free air burst.

$$\frac{1}{W^{1/3}} = \frac{1}{1.8^{1/3}} = 0.82207$$

Data in the following table was obtained from #1344 and scaled by the factor, $\lambda = 0.82207$. Comparison Range 6951.7 - 1.7 psi

Distance (ft/LB$^{1/3}$)	λ x Distance (ft/lb$^{1/3}$)	Overpressure (psi)
0.2	0.16	6951.7
0.25	0.21	5599.0
0.3	0.25	4623.8
0.4	0.33	3340.9
0.5	0.41	2552.6
0.8	0.66	1367.7
1.0	0.82	993.5
1.5	1.23	533.4
2.0	1.64	325.9
3.0	2.47	133.7
5.0	4.11	41.8
10.0	8.22	9.6
15.0	12.33	4.6
20.0	16.44	2.9
30.0	24.66	1.7

4) Attachment #8 (opposite), a 1000 LB TNT free air curve provided by John Keefer of BRL.

Work continued. Gerald Bulmash 4/9/82

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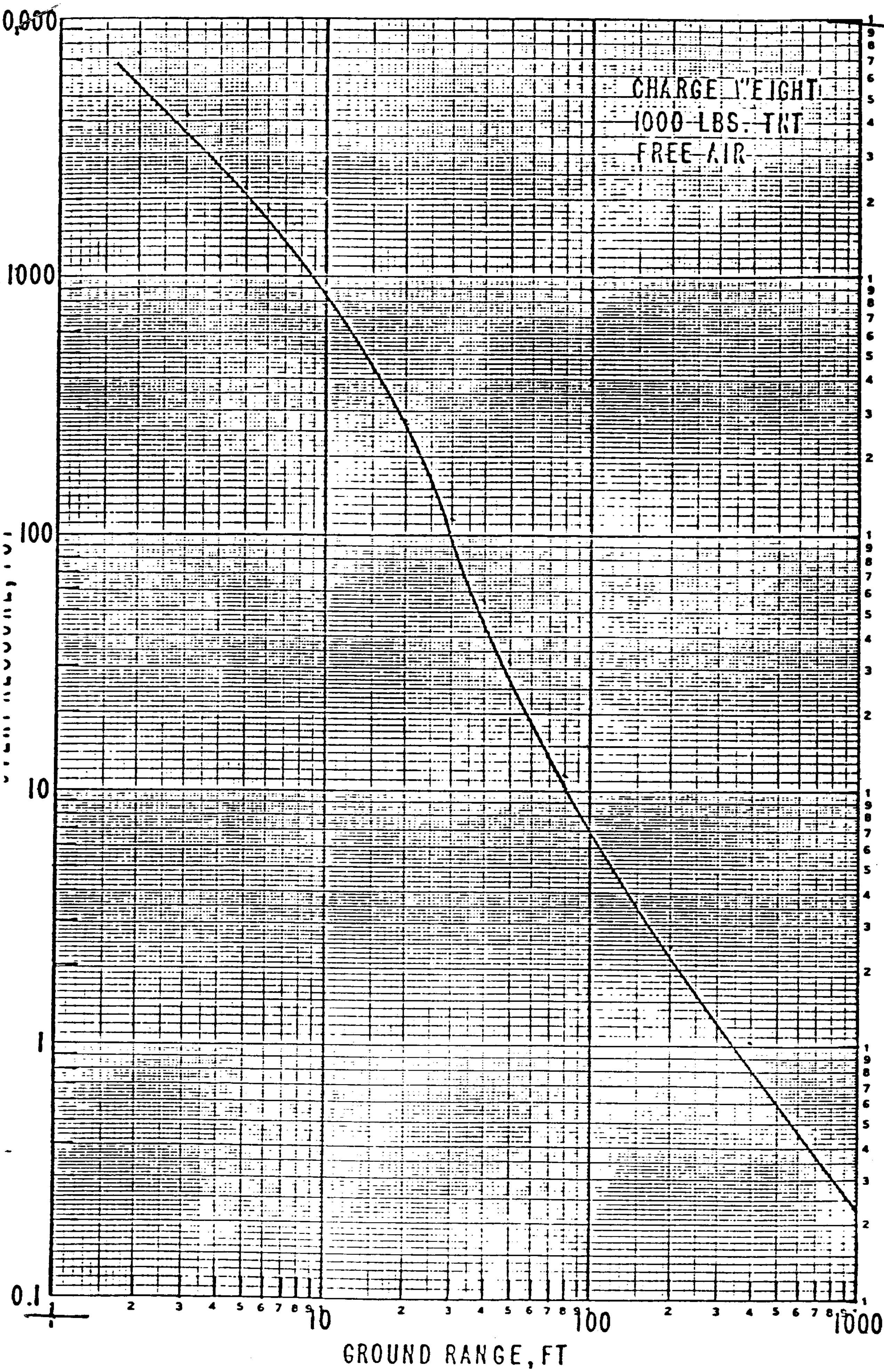
1000 LBS TNT - FREE AIR



ATTACHMENT #8

(provided by John Keefer)

TLE DDESB Analysis Book No.

From Page No. 8

Data points obtained from the 1000 LB TNT curve scaled to 1 LB TNT. Comparison Range 6000 - 0.7 psi.

Distance ($Ft/LB^{1/3}$)	Overpressure (Psi)
0.18	6000.0
0.22	5000.0
0.275	4000.0
0.42	2500.0
0.87	1000.0
1.4	500.0
2.3	200.0
2.9	100.0
3.8	50.0
5.6	20.0
8.2	10.0
12.0	5.0
21.5	2.0
34.0	1.0
44.2	0.7

5) Comparisons by observation were also conducted with TM5-1300, Figure 4-5 and the Pantex Manual, "A Manual For The Prediction of Blast and Fragment Loadings on Structures", DOE/TIC -11268, November, 1980 (Figure 4.5).

B. Reflected Pressure

i) BRL Reports #1950 and # 1990

Distance ($Ft/lb^{1/3}$)	Reflected Pressure (Psi)
2.36	836.2
2.86	561.1
3.56	262.8
4.54	105.0
5.85	71.2
7.00	39.1
8.691	23.39
11.578	13.89
13.867	10.05

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Work continued

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From Page No. 9

2) BRL Report #1249, "Parametric Analysis of the Regular Reflection of Air Blast", Kingery and Pannill, June, 1964. This report contains data tables displaying incident pressures and theoretically calculated reflected pressures based on these incident pressures. I compared the data from #1249 by using the following procedure. Obtain an incident pressure value at 0.0 feet horizontal distance from the charge, ie, a normally reflected station, from #1249. Also obtain the normally reflected record at this station (the theoretical calculation). Locate the scaled distance on the TM5-1300 curve where this same incident pressure can be obtained. Then find the reflected pressure at this distance on the TM5-1300 reflected pressure curve.

Distance ($Ft/LB^{1/3}$)	Reflected Pressure (Psi)
0.3	50475.5
0.4	33841.7
0.6	18320.9
1.0	7628.8
1.4	3431.4
2.4	982.6
3.0	455.1
3.5	237.28
7.0	30.7
9.0	18.1
13.0	8.75
20.0	4.56

3) Comparisons by observations were also conducted with TM5-1300, Figure 4-5 and Pontyl Manual, Figure 4.6.

C. Incident Impulse

1) BRL Reports #1950 and #1990

Work continued. Gerald Bulanh 4/13/82

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Distance (Ft/LB^1/3)	Incident Impulse (Psi-msec/LB^1/3)
2.01	21.76
2.46	18.17
3.00	15.18
4.48	10.70
7.39	6.75
12.18	4.14
20.09	2.66
24.53	2.25

2) BRL Report #1344. Hemispherical TNT Surface Burst Data was scaled to a comparable free air spherical TNT burst. Scaling was performed both for distance and impulse. As indicated on page 8, $\lambda = 0.82207$.

λ X Distance (Ft/lb^1/3)	λ X Impulse (Psi-msec/LB^1/3)
0.41	34.69
0.58	21.95
0.82	16.44
0.99	15.54
1.23	15.29
1.40	15.78
1.64	18.41
1.97	21.78
2.30	20.63
2.88	17.35
4.11	12.41
6.58	8.10
8.22	6.66
16.44	3.53
24.66	2.41
32.88	1.82

3) Comparisons by observation were also conducted with TM5-1300 and the Panter Manual.

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D. Reflected Impulse.

1) BRL Reports #1950 and #1990.

For many of the experimental shots in the Canadian series reported in #1950 and #1990 it was not possible to obtain good normally reflected impulse data. In #1950 there were not any ~~[illegible]~~ recording stations directly below the charge. The closest station for shots 1 thru 10 was at a horizontal distance of 2 feet from ground zero. Since these shots were fired at low heights of burst (5.4 to 71.9 feet), in the extreme case of the lowest HOB the closest recording station was 22° from being a normally reflecting station.

Distance ($Ft/LB^{\frac{1}{3}}$)	Reflected Impulse ($Psi\text{-}msec/LB^{\frac{1}{3}}$)
2.36	70.9
2.86	55.3
3.56	43.9
4.54	36.6
5.85	27.4
7.00	23.0
8.691	14.03
11.578	10.19
13.867	8.31

2) BRL Report #1092, "Compiled Free-Air Blast Data On Bare Spherical Pentolite", H. J. Goodman, Feb. 1960. Although #1092 is a compilation of Pentolite data, it is an excellent source for reduced reflected impulse data. I scale from Pentolite to TNT by using $(1.17)^{-\frac{1}{3}}$, the Pentolite to TNT equivalency factor.

Work continued. Gerald Bulmash 4/13/82

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Distance (Ft/LB^1/3)	Reflected Impulse (Psi-msec/LB^1/3)
0.1256	9825.9
0.1883	4336.0
0.2511	2483.5
0.3139	1634.2
0.5649	576.2
1.0667	207.0
1.7575	100.1
2.0090	83.3
2.5111	61.89
3.5151	40.34
4.5201	29.71
7.0311	17.77
9.5374	12.62
12.555	9.359
17.575	6.533
21.969	5.165

Gerald Bulmash 4/13/82

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Project No.
TITLE DDESB Analysis Book No.

From Page No. (3) Recommendation for the revision of the Spherical TNT Free Air Blast Parameter Curves included in TM5-1300.

Based on the data reduction and analysis heretofore mentioned I recommended revised air blast parameters as summarized on attachment # 9A (opposite) and # 9B (next page) which is a photocopy of a letter to the Arradcom project officer for the manual revision.

Significant changes are: 1) Incident pressure curve extended to 0.7 psi since blast damage can occur in this relatively low pressure region. 2) Change incident impulse to include a local maximum at about 2 ft. which is due to an irregularity in the positive phase duration curve. 3) Extend all curves inward to a scaled distance of 0.13 feet which is the beginning of the curve with the charge surface. 4) Extend reflected impulse to 100 feet by extrapolating.

After the revised air blast parameters were developed, I used a Tektronix 4051 minicomputer to develop functions to represent the curves. Employing the "Plot 50, Mathematics, Volume II" by Tektronix and a logarithmic graphing program by Rodney Abrahams of BRL and several interfacing subroutines that I developed, curves were generated from accurately fitting Polynomial Regression and Chebyshev Fit functions. See attachment # 10 as an example (opposite page 16). Then I wrote a computer program to place the functions and curves on the BRL mainframe computer, a CDC 173-7600 mainframe combination. See attachments # 11 A-D (opposite page 16).

Functions for these curves are as follows:

<u>Incident pressure</u>: 7the degree polynomial regression.
From 0.13 - 49.4 ft.
From 7200 - 0.7 psi.

$$X' = 1.4288 * X - 0.5712$$

Work continued Gerald Bulmash 4/22/82 To Page No

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DEPARTMENT OF THE ARMY
U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
U.S. ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND 21005

ATTACHMENT # 9A

REPLY TO
ATTENTION OF

DRDAR-BLT

8 January 1982

SUBJECT: Revision of the Protective Structures Manual, TM5-1300

Commander
USARRADCOM
ATTN: DRDAR-LCM-SP/J. Caltagirone
Building 321
Dover, NJ 07801

1. BRL has performed the following tasks under the direction of Mr. Charles Kingery for the revision of TM5-1300.

I. We have developed a set of curves for P_r/P_i vs. angle of incidence for overpressures from 0.2 to 5000 psi. This graph was created by converting Brode's curves from cotangent of the angle to angle of incidence which provided values in the range from 14.7 to 90 degrees. To complete the task BRL obtained values in the 0 to 14.7 degree range by interpolating from Figures 4-6 of TM5-1300 and BRL Report No. 1249, Kingery & Pannill, "Parametric Analysis of the Regular Reflection of Air Blast", 1964. This set of curves is essentially Brode's curves in a different format. Inclosed find: (1) A complete set of curves on one graph with and without labels; (2) An individual graph of each curve; and (3) A listing of the points used to create these curves.

II. We have revised the spherical TNT free air curves for incident and reflected pressure and incident and reflected impulse. For each of these parameters, inclosed find: (1) A graph showing BRL's recommendation; (2) A listing of the points used to create the curve; and (3) A graph comparing our recommendation with several sources of data. In addition to these sources we relied on the original TM5-1300 curves and Dr. Baker's curves.

BRL recommendations are as follows:

A. Incident Pressure

Data from several sources substantively agrees with TM5-1300, Figures 4-5. We extended this curve to 0.7 psi by inclusion of points based on Figure 1 (Basis for NSWC/WOL/TR75-116) of the 16 June 81 subcommittee meeting minutes. BRL recommends the inclosed curve.

ATTACHMENT #9B

:DAR-BLT 8 January 1982

JBJECT: Revision of the Protective Structures Manual TM5-1300

On the inclosed graph of incident pressure comparing four sources, NSWC refers to this Figure 1. Another souce for comparison is listed as BRL Reports No.1950 and No.1990 on this graph. These are two reports by Reisler, Pettit, and Kennedy, "Air Blast Data from Height-of-Burst", Volume I, 1976 and Volume II, 1977. These reports provide data from 1.63 - 230.4 psi. Although we could provide error bands for the data, this is just one of several sources used in arriving at a final curve. This is 1000 lb. TNT data.

BRL Report No. 1344 is "Air Blast Parameters vs. Distance for Hemispherical TNT Surface Bursts", Kingery, 1966.

The reference to Keefer on the comparison graph refers to the 1000 lb. TNT free air curve provided by John Keefer of BRL. This is Graph III of Inclusion 3 to Inclusion 1 of the 24 Nov 81 subcommittee meeting minutes.

B. Reflected Pressure

Available reflected pressure data also agrees with TM5-1300, Figures 4-5, and BRL recommends that this curve continue to be used. The inclosed curve is substantively the same as the curve already in TM5-1300.

C. Incident Impulse

BRL recommends a curve similar to Dr. Baker's curve. BRL's curve was generated by scaling data from BRL Report No. 1344 to the cube root of 1.8 and results in impulse measurements which are slightly higher than Dr. Baker's curve and BRL Report No. 1950 and No. 1990 data. This curve was extrapolated from 0.4 to 0.15 feet, because no data is available in this region.

D. Reflected Impulse

BRL recommends the inclosed curve which was arrived at by scaling the pentolite curve in BRL Report No. 1092 ("Compiled Free Air Blast Data on Bare Spherical Pentolite", Goodman, 1960) to TNT by using the cube root of 1.17, the pentolite to TNT equivalency factor. This curve was extrapolated from 22.6 - 100 feet.

We would be glad to discuss any questions or comments regarding this .terial.

Gerald Bulmash

Incls

GERALD BULMASH

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TITLE — DDESB Analysis Book No.______ 1

From Page No 14

$Y = 2.1458 - 1.611*X' - 0.2093*X'^2 + 0.3046*X'^3 + 0.0712*X'^4 - 0.0651*X'^5 - 0.0103*X'^6 + 0.0061*X'^7$.

All constants, distance, and pressure are in log form.

X is the $\log_{10}$ of the scaled distance.
X' is an intermediate calculation.
Y is the $\log_{10}$ of the overpressure.

10^Y = overpressure. See attachment #11A for the curve

Similarly, the following 3 functions are in log form.

Incident Impulse: Two functions were required to accurately fit this curve.

1) 5th degree Chebyshev fit
from 0.13 - 1.97 feet (the local maximum)
from 3027 - 22.4 Psi-msec.

$Y = 1.1967 - 0.2010*X + 1.7470*X^2 + 1.0450*X^3 + 3.5859*X^4 + 3.2020*X^5$

2) 3rd degree Chebyshev fit
from 1.97 to 56.8 ft
from 22.4 to 1.1 Psi-msec.

$Y = 1.5213 - 0.4673*X - 0.4232*X^2 + 0.1183*X^3$

See attachment #11 B.

Reflected Impulse: 3rd degree Chebyshev fit.
From 0.13 feet to 100 feet.
From 9300 to 1.0 Psi-msec.

$Y = 2.3634 - 1.5134*X + 0.2849*X^2 - 0.0585*X^3$

See attachment #11 D.
Work continued. Gerald Bulmash 4/22/52

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Reflected Pressure: Two functions

1) 3rd degree Chebyshev fit.
From 0.13 - 3.2 feet.
From 97000 - 420.1 psi

Y = 3.8587 - 1.9630*X - 0.8890*X^2 - 0.1290*X

2) 5th degree Chebyshev fit.
From 3.20 - 46.8 feet
From 420.1 to 1.6 psi

Y = 1.8927 + 12.089*X - 36.388*X^2 + 38.949*
-18.798*X^4 + 3.420*X^5

See attachment # 11C.

On 4/15/82 at a meeting of the "Steering Committee For the Revision of the Protective Structures Manual TM5-1300) in Dover (Arradcom), the revised air blast parameters were accepted for inclusion in TM5-1300 and BRL was requested to provide similar functions, curves, and incremental listings for time of arrival, duration, and shock velocity. It was also requested that BRL provide a complete set of parameters with functions, curves and incremental listings, based on Charles Kingery's report # 1344, for hemispherical TNT surface bursts.

Work completed. G Bulmash 4/22/82

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Revision of incident pressure based on BRL report # 1344, "Air Blast Parameters vs. Distance for Hemispherical TNT Surface Burst," by C.N. Kingery. Values from this report were extrapolated to the charge surface which was calculated to be 0.16845 feet from the charge center.

Density of pressed TNT = 1.6 gm/cc

= .057803667 LB/in^3

17.29994045 in^3/LB of TNT

Volume of 1 LB = $\frac{4}{3}\pi r^3$ for a sphere.

For a hemisphere = $\frac{2}{3}\pi r^3$

Therefore r = 0.1684537768 feet.

Attachment # 18 (opposite) is a listing of the revised incident pressure data points.

Attachment # 19 (below) is a program listing of the polynomial regression function developed to fit the data. Limits and equations are log values.

Attachment #19

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y-(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.8861
835 K5=1.7542
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=1.3913*K8-0.7189
880 K9=2.0411-1.6129*K4-0.2224*K4^2+0.3336*K4^3
881 K9=K9+0.148*K4^4-0.155*K4^5-0.0478*K4^6
882 K9=K9+0.0359*K4^7+0.0065*K4^8-0.0033*K4^9-3.0E-4*K4^10
885 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
910 END
```

Work Completed 6/25/82 G. Bulmash

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HEMISP-
-HERICAL SURFACE BURST Attachment #18 A

SCALED DISTANCE (Ft/Lb^(1/3))	SCALED INCIDENT PRESSURE (Psi)
0.120	10,700.000
0.130	10,050.000
0.150	8,950.000
0.160	8,450.000
0.180	7,700.000
0.190	7,300.000
0.200	6,952.000
0.250	5,599.000
0.300	4,624.000
0.350	3,897.000
0.400	3,341.000
0.450	2,904.000
0.500	2,553.000
0.550	2,264.000
0.600	2,022.000
0.650	1,818.000
0.700	1,645.000
0.750	1,497.000
0.800	1,368.000
0.850	1,255.000
0.900	1,157.000
0.950	1,070.000
1.000	993.500
1.100	860.200
1.200	754.400
1.300	667.800
1.400	592.300
1.500	533.400
1.600	478.200
1.700	432.200
1.800	391.900
1.900	354.000
2.000	320.700
2.200	263.000
2.400	218.000
2.600	183.400
2.800	155.800
3.000	133.700
3.250	111.700
3.500	94.380
3.750	80.640
4.000	69.580
4.500	53.160
5.000	41.840
5.500	33.760
6.000	27.820
6.500	23.340

Attachment #18 B

48)	7.000	19.890
49)	7.500	17.180
50)	8.000	15.010
51)	8.500	13.230
52)	9.000	11.820
53)	9.500	10.590
54)	10.000	9.615
55)	11.000	8.029
56)	12.000	6.825
57)	13.000	5.920
58)	14.000	5.186
59)	15.000	4.665
60)	16.000	4.177
61)	17.000	3.797
62)	18.000	3.488
63)	19.000	3.208
64)	20.000	2.984
65)	22.000	2.596
66)	24.000	2.299
67)	26.000	2.061
68)	28.000	1.867
69)	30.000	1.706
70)	32.500	1.537
71)	35.000	1.397
72)	37.500	1.279
73)	40.000	1.178
74)	45.000	1.015
75)	50.000	0.888
76)	55.000	0.786
77)	60.000	0.702
78)	65.000	0.633
79)	70.000	0.574
80)	75.000	0.522
81)	80.000	0.477
82)	90.000	0.404

TITLE DDESB Analysis

Book No.

From Page No. Hemispherical Surface Burst - Incident Impulse.

Based on report #1344, incident impulse was extrapolated from 0.499 feet inward to the charge surface, 0.16895 feet

Attachment # 20 (opposite) is a listing of the revised incident data points. Since the data shows a local maximum value at about 2.4 feet, it was necessary to divide the data into two segments from 0.12 - 2.396 feet and 2.396 - 69.99 feet when deriving the equations to fit the data. Attachment #21 shows these fu below.

Attachment #21

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.9208
835 K5=0.3796
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=3.076*K8+0.8325
880 K9=1.5716-0.503*K4+0.1713*K4^2+0.045*K4^3
881 K9=K9-0.0119*K4^4
885 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
910 END
920 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
930 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
940 K1=0.3795
950 K5=1.8451
960 M4=0
970 DELETE M7,M8
980 M9=INT((K5-K1)/0.01)+1
990 DIM M7(M9),M8(M9)
1000 FOR K8=K1 TO K5 STEP 0.01
1010 K4=2.729*K8-3.036
1020 K9=0.8082-0.3333*K4-0.0172*K4^2+0.0026*K4^3
1030 K9=K9+0.0108*K4^4-0.0052*K4^5-0.0023*K4^6
1040 K9=K9+0.0012*K4^7
1050 M5=10^K8
1060 M5=FNA(M5)
1070 M6=10^K9
1080 M6=FNB(M6)
1090 M4=M4+1
1100 M7(M4)=M5
1110 M8(M4)=M6
1120 NEXT K8
1130 END
```

Work Continued.

To Page

G. Bultmann

Witnessed & Unders

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Attachment #20

HEMISPHERICAL SURFACE BURST

	DIST. (ft) X	IMPULSE (psi-msec) Y
1)	0.120	520.000
2)	0.140	430.000
3)	0.158	365.000
4)	0.182	298.028
5)	0.243	178.817
6)	0.304	103.398
7)	0.365	72.986
8)	0.426	52.307
9)	0.499	42.198
10)	0.706	26.701
11)	0.997	19.998
12)	1.204	18.903
13)	1.496	18.599
14)	1.703	19.195
15)	1.995	22.395
16)	2.200	24.500
DIVISION POINT → 17)	2.396	26.494
18)	2.600	26.300
19)	2.798	25.095
20)	3.503	21.105
21)	5.000	15.096
22)	8.004	9.853
23)	9.999	8.101
24)	19.998	4.294
25)	29.997	2.932
26)	39.997	2.214
27)	49.996	1.788
28)	59.995	1.484
29)	69.994	1.277

TITLE DDESB Analysis

Project No.________

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From Page No. 23

Hemispherical Surface Burst – Revised Free Air Burst Incident Impulse.

The graph (attachment 11B, opposite page 16) of spherical free air incident impulse shows a local peak. Since this sharply pointed peak actually represents a continuous rounded curve, I revised the original polynomial regression functions representing the data to show the rounded peak.

Attachment #22 (below) is a program listing of the revised free air functional representation.

Attachment #22

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.939
835 K5=0.3
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=3.243*K8+1.045
880 K9=1.4353-0.4437*K4+0.1688*K4^2+0.0348*K4^3
881 K9=K9-0.0104*K4^4
885 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
910 END
920 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
930 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
940 K1=0.3
950 K5=1.76
960 M4=0
970 DELETE M7,M8
980 M9=INT((K5-K1)/0.01)+1
990 DIM M7(M9),M8(M9)
1000 FOR K8=K1 TO K5 STEP 0.01
1010 K4=2.729*K8-2.804
1020 K9=0.7231-0.3333*K4-0.0172*K4^2+0.0026*K4^3
1030 K9=K9+0.0108*K4^4-0.0052*K4^5-0.0023*K4^6
1040 K9=K9+0.0012*K4^7
1050 M5=10^K9
1060 M5=FNA(M5)
1070 M6=10^K9
1080 M6=FNB(M6)
1090 M4=M4+1
1100 M7(M4)=M5
1110 M8(M4)=M6
1120 NEXT K8
1130 END
```

Work completed 7/3

To Page No.

Date G Bulmer

Witnessed & Unders

Recorded by

TITLE DDESB Analysis Book No.

From Page No. Hemispherical Surface Burst - Shock Front Velocity.

Shock Front Velocity based on report #1344. Values from 0.2 feet to 0.16845 feet extrapolated from report #1344

Attachment #23 (opposite) shows the data points. Attachment #24 (below) is a program listing of the functional representation

Attachment #24

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.7031
835 K5=2
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=1.37784223635*K8-0.755684472698
880 K9=0.449774310005-0.698029762594*K4+0.158916781906*K4^2
881 K9=K9+0.443212098136*K4^3-0.113402023921*K4^4
882 K9=K9-0.369887075049*K4^5+0.129230567449*K4^6
883 K9=K9+0.19857981197*K4^7-0.0867636217397*K4^8
884 K9=K9-0.0620391900135*K4^9+0.0307482926566*K4^10
885 K9=K9+0.0102657234407*K4^11-0.00546533250772*K4^12
886 K9=K9-6.93180974E-4*K4^13+3.847494916E-4*K4^14
888 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
910 END
```

Work continued. G Bulmash

To Page No.:

Witnessed & Understood by me,	Date	Invented by	Date
		Recorded by	

Attachment #23 A

	DIST (ft)	SHOCK FRONT VELOCITY (Ft/sec)
1)	0.125	26.057
2)	0.136	25.119
3)	0.150	24.159
4)	0.168	23.143
5)	0.188	22.082
6)	0.200	21.518
7)	0.250	19.366
8)	0.300	17.645
9)	0.350	16.230
10)	0.400	15.048
11)	0.450	14.046
12)	0.500	13.182
13)	0.550	12.431
14)	0.600	11.770
15)	0.650	11.183
16)	0.700	10.659
17)	0.750	10.187
18)	0.800	9.759
19)	0.850	9.369
20)	0.900	9.012
21)	0.950	8.684
22)	1.000	8.381
23)	1.100	7.830
24)	1.200	7.356
25)	1.300	6.940
26)	1.400	6.562
27)	1.500	6.236
28)	1.600	5.928
29)	1.700	5.651
30)	1.800	5.394
31)	1.900	5.144
32)	2.000	4.910
33)	2.200	4.479
34)	2.400	4.110
35)	2.600	3.798
36)	2.800	3.531
37)	3.000	3.299
38)	3.250	3.051
39)	3.500	2.841
40)	3.750	2.661
41)	4.000	2.507
42)	4.500	2.261
43)	5.000	2.070

Attachment #23 B

	DIST (ft)	SHOCK FRONT VELOCITY (Ft/sec)
44)	5.500	1.924
45)	6.000	1.807
46)	6.500	1.715
47)	7.000	1.641
48)	7.500	1.579
49)	8.000	1.529
50)	8.500	1.486
51)	9.000	1.451
52)	9.500	1.420
53)	10.000	1.395
54)	11.000	1.353
55)	12.000	1.320
56)	13.000	1.295
57)	14.000	1.274
58)	15.000	1.259
59)	16.000	1.245
60)	17.000	1.234
61)	18.000	1.225
62)	19.000	1.216
63)	20.000	1.209
64)	22.000	1.198
65)	24.000	1.189
66)	26.000	1.181
67)	28.000	1.176
68)	30.000	1.171
69)	32.500	1.165
70)	35.000	1.161
71)	37.500	1.157
72)	40.000	1.154
73)	45.000	1.149
74)	50.000	1.145
75)	55.000	1.142
76)	60.000	1.139
77)	65.000	1.137
78)	70.000	1.135
79)	75.000	1.133
80)	80.000	1.132
81)	90.000	1.129
82)	100.000	1.128

Project No.
Book No.

TITLE DDESB Analysis

From Page No. 25 Hemispherical Surface Burst - Arrival Time

Values obtained from BRL report # 1344 with extrapolation to the charge surface based on shock front velocity.

Attachment # 25 is an incremental listing of the data points. Attachment # 26 (below) is the functional representation of the data.

Attachment # 26

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(Q)=Y-(Y1-Y)*(LGT(Q)-LGT(Y2))/Y6
820 K1=-0.9031
835 K5=2
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=1.37784223635*K8-0.735664472698
880 K9=-0.17360760125l+1.35706496258*K4+0.052492798645*K4^2
881 K9=K9-0.196563954086*K4^3-0.0601770052288*K4^4
882 K9=K9+0.0696360270891*K4^5+0.0215297490092*K4^6
883 K9=K9-0.0161658930785*K4^7-0.00232531970294*K4^8
884 K9=K9+0.00147752067524*K4^9
888 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
910 END
```

Work completed. 7/9/82 G B [signature]

To Page No.

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

Attachment #25 A

	DIST (Ft)	ARRIVAL TIME (Msec)
	0.125	0.006
	0.136	0.007
	0.150	0.007
	0.168	0.008
	0.188	0.009
	0.200	0.010
	0.250	0.012
	0.300	0.015
	0.350	0.018
	0.400	0.021
	0.450	0.024
	0.500	0.028
	0.550	0.032
	0.600	0.036
	0.650	0.040
	0.700	0.045
	0.750	0.050
	0.800	0.055
	0.850	0.060
	0.900	0.065
	0.950	0.071
	1.000	0.077
	1.100	0.089
	1.200	0.103
	1.300	0.117
	1.400	0.131
	1.500	0.147
	1.600	0.163
	1.700	0.181
	1.800	0.199
	1.900	0.218
	2.000	0.238
	2.200	0.280
	2.400	0.327
	2.600	0.378
	2.800	0.432
	3.000	0.491
	3.250	0.570
	3.500	0.655
	3.750	0.746
	4.000	0.843
	4.500	1.053
	5.000	1.284
	5.500	1.535
45)	6.000	1.803
46)	6.500	2.087
47)	7.000	2.385
48)	7.500	2.696
49)	8.000	3.018
50)	8.500	3.349
51)	9.000	3.690
52)	9.500	4.037
53)	10.000	4.393
54)	11.000	5.121
55)	12.000	5.868
56)	13.000	6.632
57)	14.000	7.408
58)	15.000	8.198
59)	16.000	8.995
60)	17.000	9.801
61)	18.000	10.610
62)	19.000	11.430
63)	20.000	12.260
64)	22.000	13.920
65)	24.000	15.600
66)	26.000	17.280
67)	28.000	18.980
68)	30.000	20.690
69)	32.500	22.830
70)	35.000	24.980
71)	37.500	27.130
72)	40.000	29.300
73)	45.000	33.640
74)	50.000	38.000
75)	55.000	42.370
76)	60.000	46.760
77)	65.000	51.150
78)	70.000	55.560
79)	75.000	59.970
80)	80.000	64.380
81)	90.000	73.230
82)	100.000	82.090

Attachment #25 B

TITLE DDESB Analysis Book No.

From Page No. Hemispherical Surface Burst - Positive Phase Duration

Positive Phase Duration data from report # 1344 has not been altered. Because the curve is rather complicated it required 3 functions to fit it. The polynomial functions listed opposite reproduce the data in the ranges of 0.450 - 2.54 ft, 2.54 - 7 feet, and 7 - 100 feet respectively (see attachment # 27).

Attachment # 28 (below) is a listing of the data used to derive the functions on the opposite page.

~~Att~~ Attachment # 28

	ft	(msec)
1)	0.450	0.197
2)	0.500	0.189
3)	0.550	0.183
4)	0.600	0.178
5)	0.650	0.174
6)	0.700	0.171
7)	0.750	0.170
8)	0.800	0.170
9)	0.850	0.171
10)	0.900	0.172
11)	0.950	0.174
12)	1.000	0.178
13)	1.100	0.190
14)	1.200	0.208
15)	1.300	0.230
16)	1.400	0.256
17)	1.500	0.288
18)	1.600	0.326
19)	1.700	0.375
20)	1.800	0.430
21)	1.900	0.510
22)	2.000	0.605
23)	2.200	0.865
24)	2.400	1.180
25)	2.600	1.430
26)	2.800	1.590
27)	3.000	1.660
28)	3.250	1.700
29)	3.500	1.700
30)	3.750	1.670
31)	4.000	1.610
32)	4.500	1.580
33)	5.000	1.570
34)	5.500	1.610
35)	6.000	1.700
36)	6.500	1.830
	7.000	2.010
38)	7.500	2.160
39)	8.000	2.290
40)	8.500	2.390
41)	9.000	2.480
42)	9.500	2.560
43)	10.000	2.620
44)	11.000	2.730
45)	12.000	2.830
46)	13.000	2.930
47)	14.000	3.010
48)	15.000	3.090
49)	16.000	3.180
50)	17.000	3.230
51)	18.000	3.310
52)	19.000	3.370
53)	20.000	3.420
54)	22.000	3.520
55)	24.000	3.640
56)	26.000	3.720
57)	28.000	3.810
58)	30.000	3.900
59)	32.500	3.990
60)	35.000	4.080
61)	37.500	4.180
62)	40.000	4.240
63)	45.000	4.400
64)	50.000	4.550
65)	55.000	4.660
66)	60.000	4.780
67)	65.000	4.870
68)	70.000	4.980
69)	75.000	5.080
70)	80.000	5.180
71)	90.000	5.330
72)	100.000	5.450

Work completed 7/16/82 G Balmore

To Page No.

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

Attachment #27

```
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.3468
835 K5=0.405
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=5.25099193925*K8-0.1790217052
880 K9=-0.728671776005+0.130143717675*K4+0.134872511954*K4^2
881 K9=K9+0.0391574276906*K4^3-0.00475933664702*K4^4
882 K9=K9-0.0042814459800B*K4^5
888 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
910 END
920 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
930 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
940 K1=0.405
950 K5=0.845
960 M4=0
970 DELETE M7,M8
980 M9=INT((K5-K1)/0.01)+1
990 DIM M7(M9),M8(M9)
1000 FOR K8=K1 TO K5 STEP 0.01
1010 K4=9.2996288611*K8-5.85909812338
1020 K9=0.20096507334-0.0297944268976*K4+0.030632954288*K4^2
1030 K9=K9+0.0183405574086*K4^3-0.0173964666211*K4^4
1040 K9=K9-0.00106321963633*K4^5+0.00562060030977*K4^6
1050 K9=K9+1.618217499E-4*K4^7-6.86018894E-4*K4^8
1080 M5=10^K8
1090 M5=FNA(M5)
1100 M6=10^K9
1110 M6=FNB(M6)
1120 M4=M4+1
1130 M7(M4)=M5
1140 M8(M4)=M6
1150 NEXT K8
1160 END
1200 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
1210 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
1220 K1=0.84
1230 K5=2
1240 M4=0
1250 DELETE M7,M8
1260 M9=INT((K5-K1)/0.01)+1
1270 DIM M7(M9),M8(M9)
1280 FOR K8=K1 TO K5 STEP 0.01
1290 K4=3.46349745571*K8-4.92699491141
1300 K9=0.57246246996 4+0.0933035304009*K4-5.849420883E-4*K4^2
1310 K9=K9-0.00226884995013*K4^3-0.00295908591505*K4^4
1320 K9=K9+0.00148029868929*K4^5
1350 M5=10^K8
1360 M5=FNA(M5)
1370 M6=10^K9
1380 M6=FNB(M6)
1390 M4=M4+1
1400 M7(M4)=M5
1410 M8(M4)=M6
```

TITLE DDESB Analyses Book No.

From Page No. — Hemispherical Surface Burst - Reflected Pressure.

Theoretical calculations for P_r were obtained from BRL report #1249, "Parametric Analysis of the Regular Reflection of Air Blast," Kingery and Pannill, by using the following equations:

$$P_r = P_2 - P_0 \qquad P_2 = P_1 \left[\frac{\left(2 + \frac{1}{\mu^2}\right)\frac{P_1}{P_0} - 1}{\left(\frac{1}{\mu^2} + \frac{P_1}{P_0}\right)} \right]$$

where, $\frac{1}{\mu^2} = \frac{\gamma + 1}{\gamma - 1} \qquad P_1 = P_s + P_0$

P_0 = 14.7 psi

P_s = incident pressure

P_r = reflected pressure, and

γ = variable ratios of specific heats.

Attachment #29 opposite is a listing of the derived values.
Attachment #30 below is a program listing of the polynomial function based on the data.

Attachment #30.

```
820 K1=-0.8861
835 K5=2
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=1.36637719229*K8-0.789312405513
880 K9=2.36431321138-2.21030870597*K4-0.218536586295*K4^2
881 K9=K9+0.895319589372*K4^3+0.24989009775*K4^4
882 K9=K9-0.569249436807*K4^5-0.11791682383*K4^6
883 K9=K9+0.224131161411*K4^7+0.0245620259375*K4^8
884 K9=K9-0.0455116002694*K4^9-0.00190930738887*K4^10
885 K9=K9+0.00361471193389*K4^11
```

Work completed. G Buhrah 7/23/82

To Page No.

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

Attachment #29

FT	Psi			
0.130	145,875.000	42)	4.500	215.000
0.150	120,929.000	43)	5.000	156.200
0.160	112,672.000	44)	5.500	117.500
0.180	100,875.000	45)	6.000	91.120
0.190	94,428.000	46)	6.500	72.540
0.200	88,817.000	47)	7.000	59.090
0.250	68,152.000	48)	7.500	49.090
0.300	54,141.000	49)	8.000	41.470
0.350	44,388.000	50)	8.500	35.490
0.400	37,504.000	51)	9.000	30.940
0.450	32,032.000	52)	9.500	27.100
0.500	27,676.000	53)	10.000	24.160
0.550	23,989.000	54)	11.000	19.540
0.600	20,896.000	55)	12.000	16.200
0.650	18,290.000	56)	13.000	13.770
0.700	16,165.000	57)	14.000	11.860
0.750	14,345.000	58)	15.000	10.540
0.800	12,821.000	59)	16.000	9.331
0.850	11,510.000	60)	17.000	8.404
0.900	10,390.000	61)	18.000	7.662
0.950	9,451.000	62)	19.000	6.998
1.000	8,634.000	63)	20.000	6.472
1.100	7,253.000	64)	22.000	5.575
1.200	6,177.000	65)	24.000	4.899
1.300	5,331.000	66)	26.000	4.365
1.400	4,594.000	67)	28.000	3.933
1.500	4,045.000	68)	30.000	3.579
1.600	3,541.000	69)	32.500	3.210
1.700	3,136.000	70)	35.000	2.906
1.800	2,782.000	71)	37.500	2.652
1.900	2,458.000	72)	40.000	2.436
2.000	2,178.000	73)	45.000	2.089
2.200	1,705.000	74)	50.000	1.821
2.400	1,350.000	75)	55.000	1.607
2.600	1,086.000	76)	60.000	1.433
2.800	882.400	77)	65.000	1.289
3.000	725.500	78)	70.000	1.168
3.250	574.400	79)	75.000	1.060
3.500	460.600	80)	80.000	0.967
3.750	374.300	81)	90.000	0.818
4.000	307.700	82)	100.000	0.704
		83)	110.000	0.615

TITLE VNES13 Analysis Book No.

From Page No. Hemispherical Surface Burst Reflected Impulse

Hemispherical surface burst reflected impulse data was obtained by scaling 1 LB pentolite to TNT and then scaling up to a 1.8 LB TNT charge.

$$I_2 = I_1 \left(\frac{1.8}{1}\right)^{1/3} \qquad D_2 = D_1 \left(\frac{1.8}{1}\right)^{1/3}$$

Pentolite data from BRL report # 1092, Henry Goodman, "Compiled Free-Air Blast Data on Bare Spherical Pentolite."

Attachment # 31 (opposite) is an incremental listing of the derived data values, and Attachment # 32 (below) is a program listing of the polynomial function which represents the data.

Attachment # 32

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.9129
835 K5=2.0851
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=1.33422049854*K8-0.781751689212
880 K9=1.75291677799-0.949516092853*K4+0.112136118689*K4^2
881 K9=K9-0.0250659183287*K4^3
885 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
910 END
```

Work completed 7/30/82 Gerald Bulmash

To Page N

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

Attachment #31

	Ft.	Psi-msec	41)	[illegible]	[illegible]
1)	0.122	19,065.000	42)	8.553	21.620
2)	0.153	11,953.000	43)	8.858	20.760
3)	0.229	5,274.500	44)	9.164	20.000
4)	0.305	3,021.000	45)	9.470	19.270
5)	0.382	1,987.900	46)	9.774	18.590
6)	0.458	1,425.700	47)	10.080	17.970
7)	0.535	1,082.900	48)	10.385	17.370
8)	0.611	857.600	49)	10.691	16.820
9)	0.687	700.900	50)	10.997	16.300
10)	0.764	587.200	51)	11.302	15.810
11)	0.840	501.400	52)	11.602	15.350
12)	0.916	435.100	53)	11.913	14.930
13)	0.993	382.600	54)	12.213	14.510
14)	1.069	340.200	55)	12.526	14.140
15)	1.145	305.300	56)	12.825	13.760
16)	1.298	251.800	57)	13.138	13.420
17)	1.375	230.900	58)	13.437	13.080
18)	1.450	213.000	59)	13.749	12.770
19)	1.527	197.300	60)	14.049	12.460
20)	1.833	151.300	61)	14.361	12.150
21)	2.138	121.800	62)	14.845	11.800
22)	2.444	101.400	63)	14.961	11.560
23)	2.749	86.530	64)	15.272	11.380
24)	3.055	75.290	65)	16.035	10.800
25)	3.360	66.540	66)	16.797	10.280
26)	3.665	59.530	67)	17.558	9.797
27)	3.971	53.820	68)	18.332	9.361
28)	4.276	49.070	69)	19.082	8.963
29)	4.582	45.070	70)	19.856	8.597
30)	4.888	41.650	71)	20.617	8.258
31)	5.193	38.710	72)	21.379	7.947
32)	5.498	36.140	73)	22.142	7.656
33)	5.803	33.880	74)	22.903	7.389
34)	6.109	31.880	75)	23.667	7.137
35)	6.415	30.110	76)	24.438	6.873
36)	6.720	28.510	77)	25.201	6.683
37)	7.026	27.080	78)	25.962	6.476
38)	7.331	25.780	79)	26.724	6.283
39)	7.636	24.600	80)	27.487	6.100
40)	7.942	23.510	81)	121.640	1.216
41)	8.247	22.520			

TITLE VIDESB Analysis Book No.

From Page No. Spherical Free Air Burst – Shock Front Velocity

Theoretical calculations of shock front velocity from overpressure were computed by using the shock-front parameter tables in BRL report # 1206 by Shear & Day, "Tables of Thermodynamic and Shock Front ~~Velocity~~ Parameters for Air."

Attachment #33 (opposite) is a listing of the data obtained. Attachment # 34 (below) is a program listing of the functional representation.

Attachment #34

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.8791
835 K5=2
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=1.389324412*K8-0.778648823994
880 K9=0.370202616212-0.652731743436*K4+0.292877813191*K4^2
881 K9=K9+0.313683288998*K4^3-0.178086227241*K4^4
882 K9=K9-0.203949310955*K4^5+0.0785813086228*K4^6
883 K9=K9+0.0980107335977*K4^7-0.0214850447971*K4^8
884 K9=K9-0.0294568546884*K4^9+0.00325445502702*K4^10
885 K9=K9+0.00480672764921*K4^11-2.10208741E-4*K4^12
886 K9=K9-3.210903529E-4*K4^13
888 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
910 END
```

Work completed 8/6/82 C Bulmk

To Page No.

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

Attachment # 33

Ft	Ft/msec
0.132	21.770
0.147	21.212
0.161	20.653
0.174	20.095
0.188	19.537
0.204	18.979
0.220	18.421
0.237	17.862
0.256	17.304
0.276	16.746
0.298	16.188
0.322	15.630
0.349	15.071
0.377	14.513
0.409	13.955
0.443	13.397
0.480	12.839
0.521	12.280
0.565	11.722
0.614	11.164
0.657	10.717
0.702	10.271
0.751	9.824
0.804	9.378
0.861	8.931
0.923	8.485
0.990	8.038
1.063	7.592
1.144	7.145
1.234	6.698
1.334	6.252
1.447	5.805
1.542	5.470
1.610	5.247
1.685	5.024
1.765	4.801
1.852	4.577
1.947	4.354
2.052	4.131
2.167	3.907
2.297	3.684
2.442	3.461
2.608	3.238
2.800	3.014
3.026	2.791
3.299	2.568
3.458	2.456
3.637	2.344
3.965	2.173

[illegible]	[illegible]	[illegible]
50)	4.192	2.071
5)	4.433	1.979
52)	4.778	1.868
53)	5.237	1.751
54)	5.533	1.688
55)	5.897	1.623
56)	6.360	1.556
57)	6.979	1.486
58)	7.870	1.412
59)	8.493	1.373
60)	9.322	1.334
61)	10.501	1.294
62)	11.312	1.273
63)	12.366	1.252
64)	13.812	1.230
65)	15.952	1.208
66)	19.515	1.186
67)	26.750	1.163
68)	33.673	1.156
69)	40.597	1.148
70)	47.521	1.140
71)	60.641	1.134
72)	73.760	1.128
73)	86.880	1.122
74)	100.000	1.117

TITLE ODESB Analysis   Book No.

From Page No. Spherical Free Air - Arrival Time.

A numerical integration routine on the Cyber 173 computer provided arrival times from shock front velocity.

$$\text{time of arrival} = \int_{\lambda_0}^{\lambda_1} \frac{d\lambda}{U} + 0.005881$$

λ = charge surface (0.1337 feet)

λ_1 = distance where arrival time is obtained

U = shock front velocity

The detonation velocity was considered to be 22,736.2 feet/sec for computing arrival time at the charge surface (0.005881 msec

Attachment #35 (opposite) is a program listing of the polynomial function derived to fit this data.

Attachment #36 (other side of this page) is a listing of the data points.

Attachment #37 (on page 32) is a comparison of arrival time values from the numerical integration with measured arrival times from the Canadian data reported in BRL reports #1950 and #1990

Work continued. 8/13/82 G Bulmash

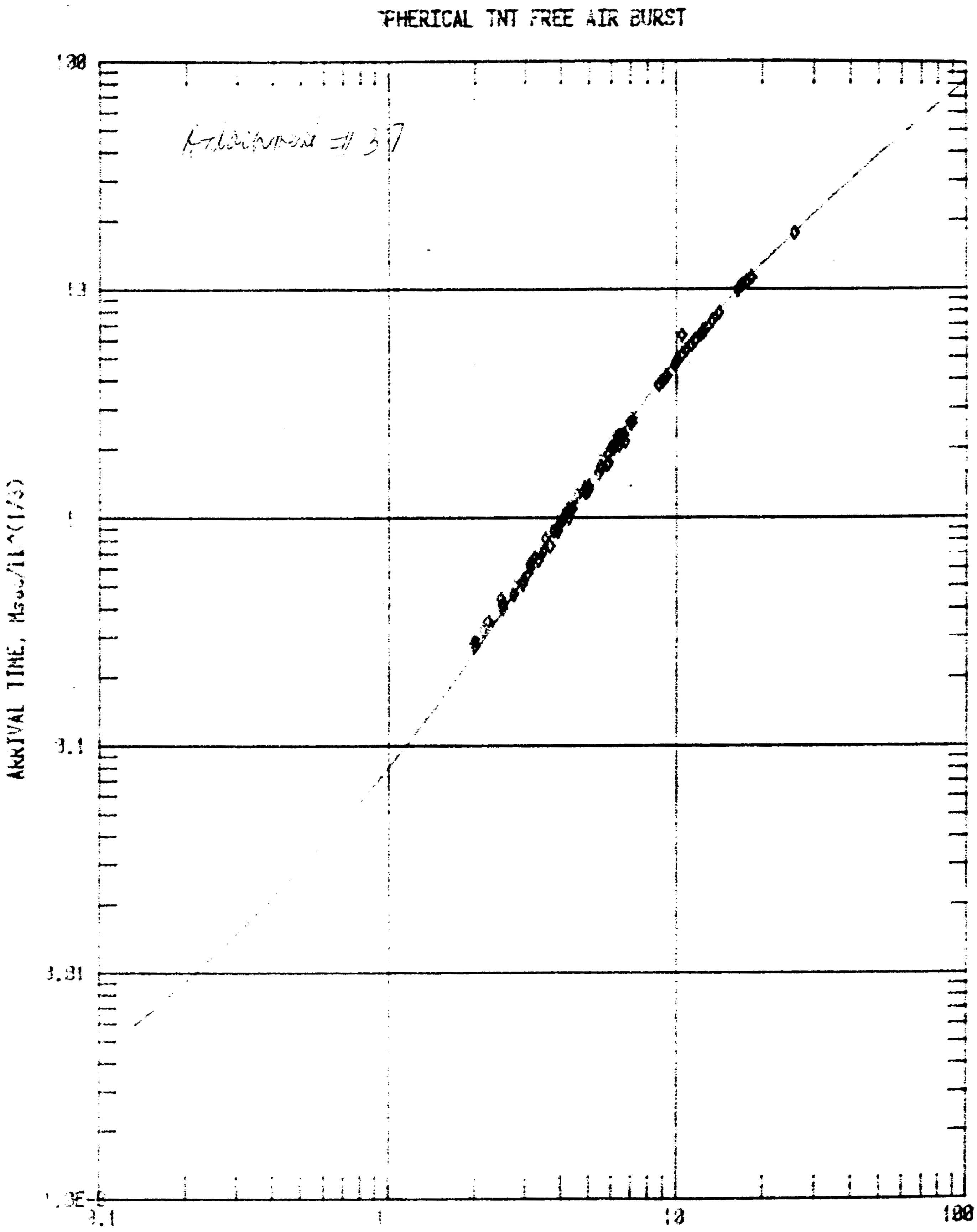
To Page No

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

Attachment #35

```
800 DEF FNA(X)=X+(X1-X)*(LGT(X)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.8739
835 K5=2
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=1.391852087 5*K8-0.783704174998
880 K9=-0.0899237047708+1.3685889205*K4-0.0331718076907*K4^2
881 K9=K9-0.199236677761*K4^3+0.00272547435549*K4^4
882 K9=K9+0.0494536222506*K4^5+4.03450304E-4*K4^6
883 K9=K9-0.00511037839674*K4^7
885 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
910 END
```

TITLE DDESB Analysis Book No.



Witnessed & Understood by me. | Date | Invented by Gerald Bulm... | Date

Recorded by

Attachment #36

	(M sec)			
		38)	1.947	0.247
0.134	0.005	39)	2.052	0.271
0.147 (H)	0.006	40)	2.167	0.300
0.161	0.007	41)	2.297	0.334
0.174	0.008	42)	2.442	0.375
0.188	0.009	43)	2.608	0.425
0.204	0.009	44)	2.800	0.486
0.220	0.010	45)	3.026	0.564
0.237	0.011	46)	3.299	0.666
0.256	0.012	47)	3.458	0.729
0.276	0.013	48)	3.637	0.804
0.298	0.015	49)	3.965	0.950
0.322	0.016	50)	4.192	1.057
0.349	0.018	51)	4.433	1.176
0.377	0.020	52)	4.778	1.355
0.409	0.022	53)	5.237	1.610
0.443	0.025	54)	5.533	1.782
0.480	0.027	55)	5.897	2.002
0.521	0.031	56)	6.360	2.294
0.565	0.034	57)	6.979	2.701
0.614	0.039	58)	7.870	3.317
0.657	0.043	59)	8.493	3.765
0.702	0.047	60)	9.322	4.378
0.751	0.052	61)	10.501	5.276
0.804	0.057	62)	11.312	5.907
0.861	0.064	63)	12.366	6.743
0.923	0.071	64)	13.812	7.909
0.990	0.079	65)	15.952	9.666
1.063	0.088	66)	19.515	12.646
1.144	0.099	67)	26.750	18.818
1.234	0.112	68)	33.673	24.793
1.334	0.128	69)	40.597	30.802
1.447	0.146	70)	47.521	36.856
1.542	0.163	71)	60.641	48.407
1.610	0.176	72)	73.760	60.001
1.685	0.190	73)	86.880	71.660
1.765	0.207	74)	100.000	83.379
1.852	0.225			

TITLE PDES 15 Analysis Book No.

From Page No. Spherical Free Air - Positive Phase Duration.

Hemispherical Surface Burst Data from report #1344 was scaled for distance and time using $(1.8)^{-1/3}$ as a scale factor.

Attachment #38 (opposite) is a listing of the calculated data points. Attachment #39 (below) is a derived set of 3 polynomial functions to fit the data.

Attachment #39 A

```
820 K1=-0.4319
835 K5=0.35
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=5.11588554305*K8+0.20944005[illegible]
880 K9=-0.801052722864+0.164953518069*K4+0.127788499497*K4^2
881 K9=K9+0.00291430135946*K4^3+0.00187957449227*K4^4
882 K9=K9+0.0173413962543*K4^5+0.00269739758043*K4^6
883 K9=K9-0.0036197650[illegible]*K4^7-0.[illegible]0100926577934*K4^8
```

#39 B

```
940 K1=0.35
950 K5=0.76
960 M4=0
970 DELETE M7,M8
980 M9=INT((K5-K1)/0.01)+1
990 DIM M7(M9),M8(M9)
1000 FOR K8=K1 TO K5 STEP 0.01
1010 K4=9.2996288611*K8-5.06778498833
1020 K9=0.115874238335-0.0297944268969*K4+0.0306329542941*K4^2
1030 K9=K9+0.0183405574074*K4^3-0.0173964666286*K4^4
1040 K9=K9-0.00106321963576*K4^5+0.[illegible]5620600312B*K4^6
1050 K9=K9+1.6182174 99E-4*K4^7-6.36[illegible]9944E-4*K4^8
```

#39 C

```
1220 K1=0.76
1230 K5=2.0288
1240 M4=0
1250 DELETE M7,M8
1260 M9=INT((K5-K1)/0.01)+1
1270 DIM M7(M9),M8(M9)
1280 FOR K8=K1 TO K5 STEP 0.01
1290 K4=3.152472536 4*K8-4.3959018[illegible]
1300 K9=0.50659210403+0.0967031995552*K4-0.00801302059667*K4^2
1310 K9=K9+0.00482705779732*K4^3+0.00187587272287*K4^4
1320 K9=K9-0.00246738509321*K4^5-8.41116668E-4*K4^6
1330 K9=K9+6.1932910 52E-4*K4^7
```

Work completed 8/20/82 G Bulmash To Page No.

Witnessed & Understood by me,	Date	Invented by	Date
		Recorded by	

Hach m cat # 38A	(M sec)	38)	6.166	1.776
0.370 (54)	0.162	39)	6.577	1.883
0.411	0.155	40)	6.988	1.965
0.452	0.150	41)	7.399	2.039
0.493	0.146	42)	7.810	2.105
0.534	0.143	43)	8.221	2.154
0.575	0.141	44)	9.043	2.244
0.617	0.140	45)	9.865	2.326
0.658	0.140	46)	10.687	2.409
0.699	0.141	47)	11.509	2.474
0.740	0.141	48)	12.331	2.540
0.781	0.143	49)	13.153	2.614
0.822	0.146	50)	13.975	2.655
0.904	0.156	51)	14.797	2.721
0.986	0.171	52)	15.619	2.770
1.069	0.189	53)	16.441	2.811
1.151	0.210	54)	18.086	2.894
1.233	0.237	55)	19.730	2.992
1.315	0.268	56)	21.374	3.058
1.398	0.308	57)	23.018	3.132
1.480	0.353	58)	24.662	3.206
1.562	0.419	59)	26.717	3.280
1.644	0.497	60)	28.772	3.354
1.809	0.711	61)	30.828	3.436
1.973	0.970	62)	32.883	3.486
2.137	1.176	63)	36.993	3.617
2.302	1.307	64)	41.104	3.740
2.466	1.365	65)	45.214	3.831
2.672	1.398	66)	49.324	3.929
2.877	1.398	67)	53;435	4.003
3.083	1.373	68)	57.545	4.094
3.288	1.324	69)	61.655	4.176
3.699	1.299	70)	65.766	4.258
4.110	1.291	71)	73.986	4.382
4.521	1.324	72)	82.207	4.480
4.932	1.398	73)	90.428	4.604
5.343	1.504	74)	98.648	4.727
5.754	1.652	75)	106.869	4.809

From Page No. Revision of Reflected Pressure and Reflected Impulse - Free Air Burst

With the exception of reflected pressure and reflected impulse functions, all of the derived functions are polynomial regressions. Therefore, in order to obtain uniformity, these two air blast parameter functions will be changed from Chebychev fits to polynomial regressions.

Reflected Impulse - Attachment #40 (below) is a polynomial function derived from the same impulse data that was used to obtain the Chebychev fit.

Attachment #40

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.901
835 K5=2
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=1.37882996018*K8-0.757659920369
880 K9=1.60579280091-0.903118886091*K4+0.101771877942*K4^2
881 K9=K9-0.0242139751146*K4^3
885 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
910 END
```

Work continued. C Bolmuth 8/27/82

To Page No. 35

TITLE DDESB Analysis

Project No.

Book No.

From Page No 34

Reflected Pressure – Revised reflected pressure values were calculated from incident pressure using a variable ratio of specific heats (γ). Reflected pressure values were obtained outward from the charge to the distance where the pressure value decreased to 0.7 psi.

Attachment #41 (opposite) is a revised listing of the data points. Attachment #42 (below) is the newly derived polynom function based on the data from attachment #41. The polynomial regression function replaces the previous Chebyshev fit

Attachment #42

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.8861
835 K5=1.9542
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875 K4=1.40930235785*K8-0.75216433862
880 K9=2.47132668689-2.1958217613*K4-0.0746338631309*K4^2
881 K9=K9+0.643995303404*K4^3+0.14282617846 2*K4^4
882 K9=K9-0.216467731056*K4^5-0.0902226140965*K4^6
883 K9=K9+0.0404761249856*K4^7+0.0229240872992*K4^8
884 K9=K9-0.0031324141 3655*K4^9-0.00212284708007*K4^10
888 M5=10^K8
890 M5=FNA(M5)
895 M6=10^K9
900 M6=FNB(M6)
902 M4=M4+1
904 M7(M4)=M5
906 M8(M4)=M6
908 NEXT K8
[illegible] END
```

Work completed. 8/27/82 E Bulmash

To Page No.

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

Attachment #4/A

(ft)	(psi)			
0.130	92,375.000	41)	4.000	181.320
0.140	88,520.000	43)	4.500	125.550
0.150	84,457.000	44)	5.000	91.000
0.160	80,387.000	45)	6.000	53.467
0.180	72,717.000	46)	6.500	42.888
0.200	65,915.000	47)	7.000	35.218
0.250	52,817.000	48)	7.500	29.512
0.300	43,844.000	49)	8.000	25.163
0.350	37,432.000	50)	8.500	21.775
0.400	32,384.000	51)	9.000	19.086
0.450	28,142.000	52)	9.500	16.917
0.500	24,608.000	53)	10.000	15.141
0.550	21,548.000	54)	11.000	12.432
0.600	18,905.000	55)	12.000	10.485
0.650	16,667.000	56)	13.000	9.035
0.700	14,723.000	57)	14.000	7.922
0.750	13,075.000	58)	15.000	7.044
0.800	11,647.000	59)	16.000	6.339
0.850	10,403.000	60)	17.000	5.761
0.900	9,342.000	61)	18.000	5.279
0.950	8,424.600	62)	19.000	4.873
1.000	7,607.100	63)	20.000	4.525
1.100	6,253.800	64)	22.000	3.963
1.200	5,191.000	65)	24.000	3.526
1.300	4,318.200	66)	26.000	3.178
1.400	3,638.100	67)	28.000	2.892
1.500	3,086.500	68)	30.000	2.653
1.600	2,634.700	69)	32.500	2.403
1.700	2,258.900	70)	35.000	2.194
1.800	1,949.100	71)	37.500	2.016
1.900	1,688.100	72)	40.000	1.862
2.000	1,469.700	73)	45.000	1.608
2.200	1,126.700	74)	50.000	1.407
2.400	877.460	75)	55.000	1.243
2.600	693.050	76)	60.000	1.106
2.800	553.700	77)	65.000	0.992
3.000	447.750	78)	70.000	0.894
3.250	348.930	79)	75.000	0.811
3.500	276.370	80)	80.000	0.739
3.750	222.110	81)	90.000	0.624

Attachment #4 B

TITLE UDESB Analysis. Book No.

From Page No. Cyber 173 Mainframe Functional Representations.

The revised air blast parameters for spherical free air one pound TNT bursts and hemispherical surface bursts of one pound TNT were represented by polynomial functions created interactively on a Tektronix 4051 minicomputer system having graphics capabilities. The functions were generated by the Tektronix Plot 50 Mathematics Vol. software package and plotted on the 4662 plotter using a program provided by Rod Abrahams of BRL.

The Cyber 173 computer was utilized, employing the Calcomp plotter and Dissplа software, to represent the air blast parameter functions in three ways. The polynomial regression functions were programmed so that the Cyber provides:

1. An incremental listing of the 7 air blast parameters vs scaled distance for surface and free air bursts. Incrementation and rounding functions were provided by Dr. T. Zaker of DDESB. See attachment 43 A+B (next page) and 44 A+B (page 38).

2. A report size plot of the parameters vs. distance for both surface and free air bursts. See attachment 45 and 46 (page

3. A poster size plot of parameters vs. distance for each free air and surface burst parameter.

Work completed 9/17/82. C Bulmash

To Page No.

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

om Page No.__ Functional Representation of TNT One Pound Charge Blast Parameters - BRL Report.

Draft Copy of report given to C.N. Kingery 10/1/82.
Report includes
1) Procedure for revision of air blast parameters for spherical free air and hemispherical surface burst of TNT.
2) Procedure for functional representation
3) Data analysis for each of 14 parameters
4) Results
Plots of free air and surface burst parameters
Tabulations for free air and surface burst parameters
5) Functions utilized to create plots and tabulations.

Work completed 10/1/82. G. Bulmash

To Page No.____

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

Page No.__ Free Air Incident Pressure.

Kingery remarked that all air blast parameters must be represented to one hundred feet. This required revision of the functions for Free Air: incident pressure, reflected pressure, shock front velocity, arrival time, and incident impulse as well as Hemispherical Surface Burst: incident pressure and incident impulse.

Free air incident pressure was extended to one hundred feet and modified to better represent the Canadian data in the midrange (230 - 1 psi). Attachment #47 (opposite) is a listing of the revised incident pressure data points. Attachment #48 (below) is the revised function, an 8th degree polynomial, that represents the free air incident pressure curve to 100 ft.

Attachment # 48

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.8861
835 K5=2.0414
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875     K4=1.35034249993*K8-0.756579301809
880     K9=1.77284970457-1.69012801396*K4+0.00804973591951*K4^2
881     K9=K9+0.336743114941*K4^3-0.00516226351334*K4^4
882     K9=K9-0.0809228619888*K4^5-0.00478507266747*K4^6
883     K9=K9+0.00793030472242*K4^7+7.684469735E-4*K4^8
885     M5=10^K8
890     M5=FNA(M5)
895     M6=10^K9
900     M6=FNB(M6)
902     M4=M4+1
904     M7(M4)=M5
906     M8(M4)=M6
908 NEXT K8
910 END
```

Work Completed 11/5/82 C. Bulmash

To Page No.____

...ssed & Understood by me.	Date	Invented by	Date
		Recorded by	

SPHERICAL TNT FREE AIR BURST

Attachment #47

	SCALED DISTANCE (Ft/Lb^(1/3))	SCALED INCIDENT PRESSURE (Psi)
1)	0.120	7,500.000
2)	0.134	7,070.000
3)	0.140	6,920.000
4)	0.160	6,400.000
5)	0.180	5,850.000
6)	0.200	5,400.000
7)	0.250	4,500.000
8)	0.300	3,820.000
9)	0.350	3,300.000
10)	0.400	2,900.000
11)	0.450	2,550.000
12)	0.500	2,240.000
13)	0.600	1,780.000
14)	0.700	1,440.000
15)	0.800	1,180.000
16)	0.900	1,000.000
17)	1.000	850.000
18)	1.200	630.000
19)	1.400	465.000
20)	1.600	350.000
21)	1.800	280.000
22)	2.000	225.000
23)	2.500	140.000
24)	3.000	92.400
25)	3.500	64.200
26)	4.000	46.900
27)	4.500	36.500
28)	5.000	28.500
29)	6.000	19.400
30)	7.000	14.000
31)	8.000	10.700
32)	9.000	8.300
33)	10.000	6.800
34)	12.000	4.900
35)	14.000	3.800
36)	16.000	3.090
37)	18.000	2.560
38)	20.000	2.230
39)	25.000	1.650
40)	30.000	1.280
41)	35.000	1.050
42)	40.000	0.880
43)	45.000	0.745
44)	50.000	0.650
45)	60.000	0.502
46)	70.000	0.410
47)	80.000	0.342
48)	90.000	0.292
49)	100.000	0.253
50)	110.000	0.223

Page No.__ Free Air Reflected Pressure.

Free Air reflected pressure was extended to 100 feet. Reflected pressure is calculated from incident pressure and a variable ratio of specific heats. See the formula on page 28. The calculations were performed on a Tektronix computer using the program listed on Attachment #50 (below). Attachment #49 (opposite) is a listing of the revised data points obtained from attachment #50

Attachment #51 (below) is the revised functional representation for reflected pressure.

Attachment #50
from P_S & variable γ

```
RUN 100
100 PRINT "PS LOWER VALUE?"
110 INPUT A
120 PRINT "PS UPPER VALUE?"
130 INPUT B
140 PRINT "PS REAL VALUE?"
150 INPUT C
160 PRINT "GAMMA (PS LOW)?"
170 INPUT E
180 PRINT "GAMMA(PS UPPER)?"
190 INPUT F
200 D=(C-A)/(B-A)
210 G=F-E
220 H=D*G
230 I=E+H
240 PRINT "GAMMA (REAL)=";I
310 Z=C
330 Y=I
340 X=14.7
350 W=Z+X
360 T=W/X
370 V=(Y+1)/(Y-1)
380 U=W*((2+V)*T-1)/(V+T)
390 S=U-X
400 PRINT "PR=";S
410 GO TO 100
420 END
```

Attachment #51

```
DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
K1=-0.8861
K5=2.0414
M4=0
DELETE M7,M8
M9=INT((K5-K1)/0.01)+1
DIM M7(M9),M8(M9)
FOR K8=K1 TO K5 STEP 0.01
   K4=1.35034249993*K8-0.756579301809
   K9=2.39106134946-2.21400538997*K4+0.035119031446*K4^
   K9=K9+0.657599992109*K4^3+0.0141818951887*K4^4
   K9=K9-0.243076636231*K4^5-0.0158699803158*K4^6
   K9=K9+0.0492741184234*K4^7+0.00227639644004*K4^8
   K9=K9-0.00397126276058*K4^9
   M5=10^K8
   M5=FNA(M5)
   M6=10^K9
   M6=FNB(M6)
   M4=M4+1
   M7(M4)=M5
   M8(M4)=M6
NEXT K8
END
```

Work completed 11/19/82 G Bulmash

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

Attachment #49

	Distance (ft)	Reflected Pressure (psi)
1)	0.120	97,690.700
2)	0.134	90,820.500
3)	0.140	88,445.500
4)	0.160	80,351.000
5)	0.180	71,981.300
6)	0.200	65,252.500
7)	0.250	52,417.400
8)	0.300	43,401.300
9)	0.350	36,956.200
10)	0.400	32,029.600
11)	0.450	27,602.600
12)	0.500	23,697.500
13)	0.600	17,833.400
14)	0.700	13,670.600
15)	0.800	10,652.900
16)	0.900	8,703.500
17)	1.000	7,141.800
18)	1.200	4,973.300
19)	1.400	3,424.300
20)	1.600	2,425.400
21)	1.800	1,843.400
22)	2.000	1,404.600
23)	2.500	770.020
24)	3.000	448.000
25)	3.500	276.490
26)	4.000	181.830
27)	4.500	130.300
28)	5.000	94.053
29)	6.000	57.243
30)	7.000	38.050
31)	8.000	27.441
32)	9.000	20.314
33)	10.000	16.127
34)	12.000	11.135
35)	14.000	8.411
36)	16.000	6.720
37)	18.000	5.493
38)	20.000	4.744
39)	25.000	3.456
40)	30.000	2.654
41)	35.000	2.164
42)	40.000	1.805
43)	45.000	1.522
44)	50.000	1.325
45)	60.000	1.019
46)	70.000	0.830
47)	80.000	0.691
48)	90.000	0.589
49)	100.000	0.510
50)	110.000	0.449

n Page No.__ Free Air Shock Front Velocity.

Free air shock front velocity was extended to 100 feet. Shock front velocity is calculated from incident pressure and variable γ using the equation listed below which was obtained from NSWC/WOL/TR 75-116.

$$① \quad U = C_0 \left(1 + \frac{\gamma+1}{2\gamma} \frac{P}{P_0} \right)^{1/2}$$

where C_0 is sound speed ahead of the shock front, P_0 = ambient pressure.

Since this equation gave unrealistically high shock front velocities for large overpressures, the complete equation for strong shock waves had to be used:

$$② \quad U = c \left(\frac{(\varepsilon - 1)(1 + \mu_s \varepsilon)}{\gamma\left[\varepsilon(\mu_s - 1) - (\mu - 1)\right]} \right)^{1/2}$$

where c is sound speed, 1116.4 ft/sec.

$$\mu_s = \frac{\gamma_s + 1}{\gamma_s - 1} \quad \text{, ie, from variable } \gamma$$

$$\mu = \frac{\gamma + 1}{\gamma - 1} \quad , \gamma = 1.402$$

$$\varepsilon = \frac{\Delta P + P}{P} \qquad P = 14.7 \text{ psi}$$

Attachment #52 (opposite) is the program used to calculate U from ②. Attachment #53 (opposite) is a listing of the revised data points obtained from the equation ②. Attachment #54 is the revised polynomial representation of free air shock front velocity.

Work completed 11/19/82 G B [signature]

Attachment #53

Distance(Ft)	SFV (Ft/msec)
0.120	22.320
0.134	21.688
0.140	21.463
0.160	20.663
0.180	19.779
0.200	19.025
0.250	17.408
0.300	16.065
0.350	14.945
0.400	14.022
0.450	13.167
0.500	12.361
0.600	11.067
0.700	10.000
0.800	9.096
0.900	8.404
1.000	7.777
1.200	6.743
1.400	5.844
1.600	5.113
1.800	4.609
2.000	4.167
2.500	3.365
3.000	2.815
3.500	2.428
4.000	2.156
4.500	1.973
5.000	1.820
6.000	1.630
7.000	1.504
8.000	1.423
9.000	1.360
10.000	1.319
12.000	1.266
14.000	1.234
16.000	1.213
18.000	1.197
20.000	1.187
25.000	1.169
30.000	1.157
35.000	1.150
40.000	1.145
45.000	1.140
50.000	1.137
60.000	1.133
70.000	1.130
80.000	1.127
90.000	1.126
100.000	1.125
110.000	1.124

Attachment #52

```
4 RUN 100
100 PAGE
105 PRINT "PS LOWER VALUE?"
110 INPUT A
120 PRINT "PS UPPER VALUE?"
130 INPUT B
140 PRINT "PS REAL VALUE?"
150 INPUT C
160 PRINT "GAMMA (PS LOW)?"
170 INPUT E
180 PRINT "GAMMA(PS UPPER)?"
190 INPUT F
200 D=(C-A)/(B-A)
210 G=F-E
220 H=D*G
230 I=E+H
240 PRINT "JGAMMA (REAL)=";I
250 J=1116.4
260 K=1.402
270 L=14.7
280 M=(C+L)/L
290 N=(I+1)/(I-1)
300 O=(K+1)/(K-1)
310 P=(M-1)*(1+N*M)
320 Q=K*(M*(N-1)-(O-1))
330 R=SQR(P/Q)
340 S=J*R
350 U=S/1000
360 PRINT "JU=";U
370 GO TO 105
380 END
```

Attachment #54

```
DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
K1=-0.8791
K5=2.0414
M4=0
DELETE M7,M8
M9=INT((K5-K1)/0.01)+1
DIM M7(M9),M8(M9)
FOR K8=K1 TO K5 STEP 0.01
   K4=1.35034249993*K8-0.756579301809
   K9=0.371369593444-0.650507560471*K4+0.291320654009*!
   K9=K9+0.307916322787*K4^3-0.183361123489*K4^4
   K9=K9-0.197740454538*K4^5+0.0909119559768*K4^6
   K9=K9+0.0898926178054*K4^7-0.0287370990248*K4^8
   K9=K9-0.0248730221702*K4^9+0.00496311705671*K4^10
   K9=K9+0.00372242076361*K4^11-3.533736952E-4*K4^12
   K9=K9-2.292913709E-4*K4^13
   M5=10^K8
   M5=FNA(M5)
   M6=10^K9
   M6=FNB(M6)
   M4=M4+1
   M7(M4)=M5
   M8(M4)=M6
NEXT K8
END
```

Project No.

Extension of parameters to 100 feet. Book No.

Page No. Free Air Arrival Time.

Arrival time was calculated from shock front velocity using the numerical integration scheme listed on attachment #55 (opposite). See page 31 for further details. Attachment #56 (left) is a listing of arrival times obtained from the numerical integration.

ft	time (sec)
~~.1~~	~~.00[illegible]~~
.18	.00810813517308
.2	.00914005053431 8
.25	.0118909514861 8
.3	.0148833717211 1
.35	.0181130563946 9
.4	.0215700785516 8
.45	.0252496382024 5
.5	.0291692242509 2
.6	.0377381359132
.7	.0472516010884 6
.8	.0577454635159 6
.9	.0692046737315 5
1.	.0815731231172
1.2	.109252657911 3
1.4	.141123638341 3
1.6	.177775302675 7
1.8	.219122970437 5
2.	.264754753097 8
2.5	.399067714377 1
3.	.562100360806 5
3.5	.754011609644 4
4.	.973238997241 9
4.5	1.21640437247 4
5.	1.48033827486
6.	2.06432524597 2
7.	2.70402224440 1
8.	3.38927700196
9.	4.10831056795 9
10.	4.85599125322 1
12.	6.40680536479 6
14.	8.00869220148 3
16.	9.64438126435
18.	11.3047575027 7
20.	12.9837174797 9
25.	17.2318694453 5
30.	21.5322472440 2
35.	25.8673150587 1
40.	30.2253691662 5
45.	34.6018748106 2
50.	38.9926457749 9
60.	47.8043860357 8
70.	56.6462447891 7
80.	65.5072233522 7
90.	74.3833003036 7
100.	83.2705285931 7
110.	92.1665878074

Attachment 56

Considering the density of TNT to be 1.56 gm/cc results in a charge radius calculation for a 1LB TNT sphere of 0.135 feet.

$$\frac{0.135 \text{ feet}}{\text{22 736.2 ft/sec TNT detonation velocity}} = 0.0059377 \text{ msec}$$

arrival time at the charge surface.

Arrival times between the charge surface and 0.18 feet were calculated by interpolation since the numerical integration required several data points before it could calculate valid results.

distance (feet)	average shock front velocity (ft/~~msec~~sec)	time (msec)
0.14	21,5737.5	0.0061695
0.16	21,062.95	0.0071190

Attachment #57 (opposite page 47) is the revised functional representation of free air arrival time.

Work completed 12/3/82. C Bulmash

To Page No.

Witnessed & Understood by me, | Date | Invented by | Date

Recorded by

Attachment #55

```
PROGRAM TOACALF(INPUT,OUTPUT)
DIMENSION X1(49),Y0(49),Y1(49),X(49),Y(49)
DATA(X1(I),I=1,5)/.135,.140,.160,.180,.2/
DATA(X1(I),I=6,10)/.25,.3,.35,.4,.45/
DATA(X1(I),I=11,15)/.5,.6,.7,.8,.9/
DATA(X1(I),I=16,20)/1.,1.2,1.4,1.6,1.8/
DATA(X1(I),I=21,25)/2.,2.5,3.,3.5,4./
DATA(X1(I),I=26,30)/4.5,5.,6.,7.,8./
DATA(X1(I),I=31,35)/9.,10.,12.,14.,16./
DATA(X1(I),I=36,40)/18.,20.,25.,30.,35./
DATA(X1(I),I=41,45)/40.,45.,50.,60.,70./
DATA(X1(I),I=46,49)/80.,90.,100.,110./
DATA(Y0(I),I=1,5)/21.6843,21.4632,20.6627,19.7790,19.0245/
DATA(Y0(I),I=6,10)/17.4079,16.0649,14.9450,14.0223,13.1672/
DATA(Y0(I),I=11,15)/12.3612,11.0665,10.0002,9.09568,8.403[illegible]/
DATA(Y0(I),I=16,20)/7.77685,6.74250,5.84443,5.11300,4.608[illegible]/
DATA(Y0(I),I=21,25)/4.16703,3.36537,2.81483,2.42750,2.165[illegible]/
DATA(Y0(I),I=26,30)/1.97268,1.82009,1.62953,1.50438,1.422[illegible]/
DATA(Y0(I),I=31,35)/1.35985,1.31918,1.26580,1.23383,1.212[illegible]/
DATA(Y0(I),I=36,40)/1.19678,1.18672,1.16884,1.15729,1.150[illegible]/
DATA(Y0(I),I=41,45)/1.14467,1.14038,1.13735,1.13261,1.12966/
DATA(Y0(I),I=46,49)/1.12747,1.12586,1.12460,1.12363/
N=49
DO 10 I=1,N
Y1(I)=1/Y0(I)
10 CONTINUE
J=2
20 J=J+1
DO 50 I=1,J
X(I)=X1(I)
Y(I)=Y1(I)
50 CONTINUE
CALL AVINT(X,Y,J,X(1),X(J),ANS)
TOA=0.0059377+ANS
PRINT*,X(J),TOA
IF(J.LT.N)GOTO 20
STOP
END
```

TITLE Extension of parameters to 100 feet.

From Page No.__ Free air incident impulse.

Free air incident impulse was extended to 100 feet. This parameter is scaled from hemispherical surface burst incident impulse data using a 1.8 equivalency factor. See page 8 concerning scaling.

Attachment # 58 (below) is a listing of the revised data points. Attachment # ~~54~~ 60 (~~opposite~~ page 48) is the revised functional representation.

Attachment #58	Dist (ft)	Impulse psi-msec
1)	0.115	353.490
2)	0.130	300.056
3)	0.150	245.000
4)	0.200	147.000
5)	0.250	85.000
6)	0.300	60.000
7)	0.350	43.000
8)	0.410	34.690
9)	0.580	21.950
10)	0.820	16.440
11)	0.990	15.540
12)	1.230	15.290
13)	1.400	15.780
14)	1.640	18.410
15)	1.809	20.141
16)	1.970	21.780
17)	2.137	21.620
18)	2.300	20.630
19)	2.880	17.350
20)	4.110	12.410
21)	6.580	8.100
22)	8.220	6.660
23)	16.440	3.530
24)	24.660	2.410
25)	32.880	1.820
26)	41.100	1.470
27)	49.320	1.220
28)	57.540	1.050
29)	65.766	0.921
30)	82.207	0.736
31)	90.428	0.662
32)	98.649	0.604
33)	106.869	0.555

Work completed 12/17/82 G B[illegible]

To Page No.____

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Attachment #57

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.8697
835 K5=2.0414
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875     K4=1.37407043777*K8-0.80501734056
880     K9=-0.0423733936826+1.36456871214*K4-0.0570035692784*K4^2
881     K9=K9-0.182832224796*K4^3+0.0118851436014*K4^4
882     K9=K9+0.0432648687627*K4^5-7.997367834E-4*K4^6
883     K9=K9-0.00436073555033*K4^7
885     M5=10^K8
890     M5=FNA(M5)
895     M6=10^K9
900     M6=FNB(M6)
902     M4=M4+1
904     M7(M4)=M5
906     M8(M4)=M6
908 NEXT K8
910 END
```

Page No. Hemispherical Surface Burst - Incident Impulse

Data was obtained from BRL report # B44.
Attachment # 59 ~~below~~ opposite is the revised functional representation.

Attachment #60

Free Air Incident Impulse

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.939
835 K5=0.31
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875     K4=3.243*K8+1.045
880     K9=1.4353-0.4437*K4+0.1688*K4^2+0.0348*K4^3
881     K9=K9-0.0104*K4^4
885     M5=10^K8
890     M5=FNA(M5)
895     M6=10^K9
900     M6=FNB(M6)
902     M4=M4+1
904     M7(M4)=M5
906     M8(M4)=M6
908 NEXT K8
910 END
920 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
930 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
940 K1=0.2944
950 K5=2.0288
960 M4=0
970 DELETE M7,M8
980 M9=INT((K5-K1)/0.01)+1
990 DIM M7(M9),M8(M9)
1000 FOR K8=K1 TO K5 STEP 0.01
1010     K4=2.30629231803*K8-2.67912519532
1020     K9=0.599008468099-0.40463292088*K4-0.0142721946082*K4^2
1030     K9=K9+0.00912366316617*K4^3-6.750681404E-4*K4^4
1040     K9=K9-0.00800863718901*K4^5+0.00314819515931*K4^6
1045     K9=K9+0.00152044783382*K4^7-7.470265899E-4*K4^8
1050     M5=10^K8
1060     M5=FNA(M5)
1070     M6=10^K9
1080     M6=FNB(M6)
1090     M4=M4+1
1100     M7(M4)=M5
1110     M8(M4)=M6
1120 NEXT K8
1130 END
```

Work completed 12/17/82 [signature]

To Page No.

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Attachment #59

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.9208
835 K5=0.38905
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875    K4=3.076*K8+0.8325
880    K9=1.5716-0.503*K4+0.1713*K4^2+0.045*K4^3
881    K9=K9-0.0119*K4^4
885    M5=10^K8
890    M5=FNA(M5)
895    M6=10^K9
900    M6=FNB(M6)
902    M4=M4+1
904    M7(M4)=M5
906    M8(M4)=M6
908 NEXT K8
910 END
920 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
930 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
940 K1=0.382
950 K5=2.0414
960 M4=0
970 DELETE M7,M8
980 M9=INT((K5-K1)/0.01)+1
990 DIM M7(M9),M8(M9)
1000 FOR K8=K1 TO K5 STEP 0.01
1010    K4=2.40697745406*K8-2.91358616806
1020    K9=0.719852655584-0.384519026965*K4-0.0260816706301*K4^2
1030    K9=K9+0.00595798753822*K4^3+0.014544526107*K4^4
1040    K9=K9-0.00663289334734*K4^5-0.00284189327204*K4^6
1045    K9=K9+0.0013644816227*K4^7
1050    M5=10^K8
1060    M5=FNA(M5)
1070    M6=10^K9
1080    M6=FNB(M6)
1090    M4=M4+1
1100    M7(M4)=M5
1110    M8(M4)=M6
1120 NEXT K8
1130 END
```

~~Free Air~~ Hemispherical Surface Burst - Incident Impulse

Page No. Hemispherical Surface Burst - Incident Pressure.
Data was obtained from BRL report #1344.
Attachment #61 below is the revised functional representation.

Attachment #61

```
800 DEF FNA(K)=X+(X1-X)*(LGT(K)-LGT(X2))/X6
810 DEF FNB(S)=Y+(Y1-Y)*(LGT(S)-LGT(Y2))/Y6
820 K1=-0.8239
835 K5=2.0414
862 M4=0
863 DELETE M7,M8
864 M9=INT((K5-K1)/0.01)+1
866 DIM M7(M9),M8(M9)
870 FOR K8=K1 TO K5 STEP 0.01
875     K4=1.35034249993*K8-0.756579301809
880     K9=1.9422502013-1.6958988741*K4-0.154159376846*K4^2
881     K9=K9+0.514060730593*K4^3+0.0988534365274*K4^4
882     K9=K9-0.293912623038*K4^5-0.0268112345019*K4^6
883     K9=K9+0.109097496421*K4^7+0.00162846756311*K4^8
884     K9=K9-0.0214631030242*K4^9+1.4567233B2E-4*K4^10
885     K9=K9+0.00167847752266*K4^11
888     M5=10^K8
890     M5=FNA(M5)
895     M6=10^K9
900     M6=FNB(M6)
902     M4=M4+1
904     M7(M4)=M5
906     M8(M4)=M6
908 NEXT K8
910 END
```

Work completed. 12/17/82. C Burlmah

To Page No.

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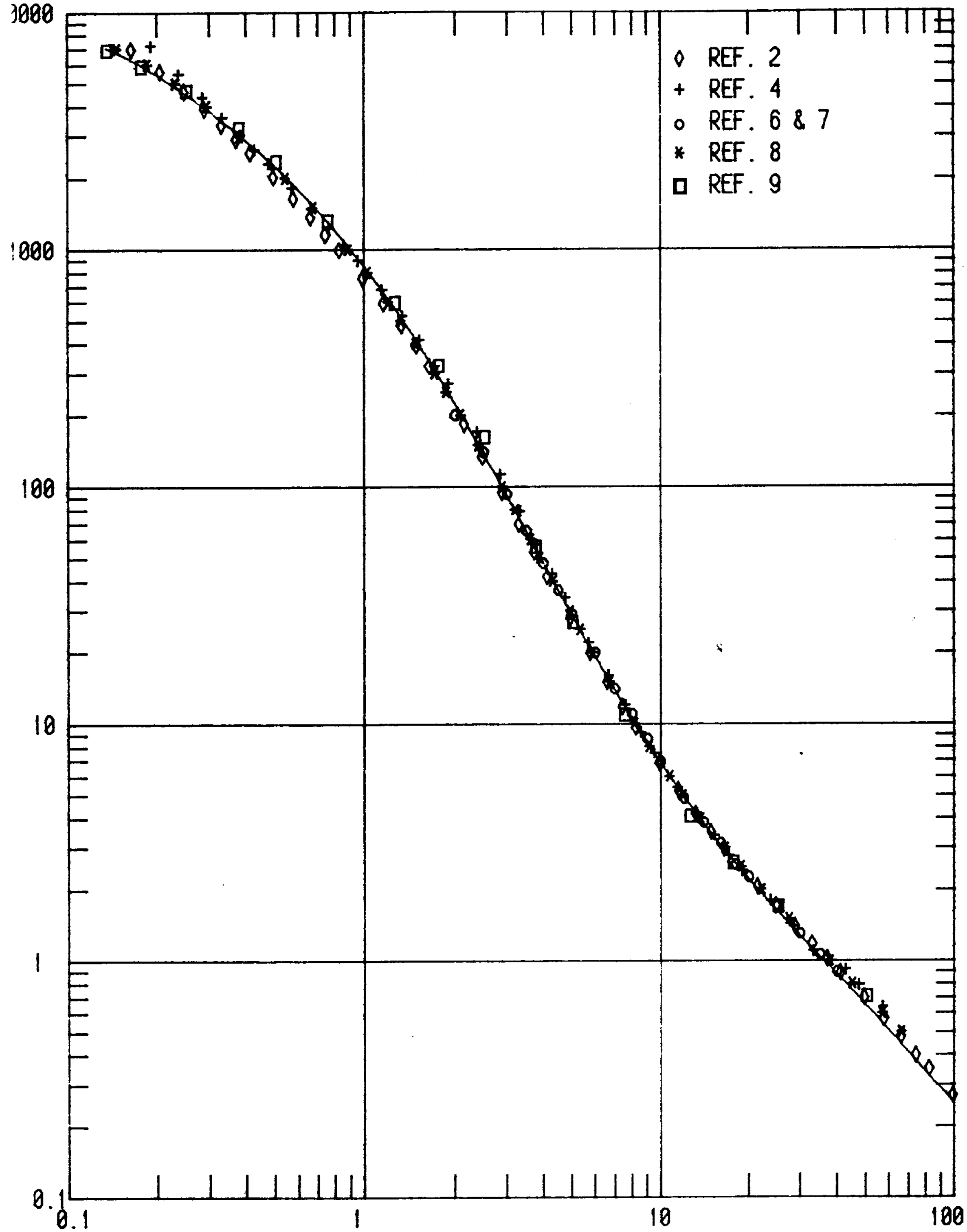
From Page No. Attachment #62 (opposite) displays the functional representation of free air incident pressure compared with various data sources. Attachment #63 (opposite page 51) compares the revised free air incident impulse curve with various sources. Attachment #64 (page 51) compares reflected impulse with data sources, and attachment #65 (opposite page 52) is a comparison of arrival time with sources.

The sources are:

Reference 2 – Hemispherical surface burst data
Reference 4 – Pentolite
Reference 6&7 – Canadian data
Reference 8 – Naval Surface Weapons Ctr.
Reference 9 – DASA 1200 (DNA)

Work continued 12/23/82 G Bulmash

Attachment # 62

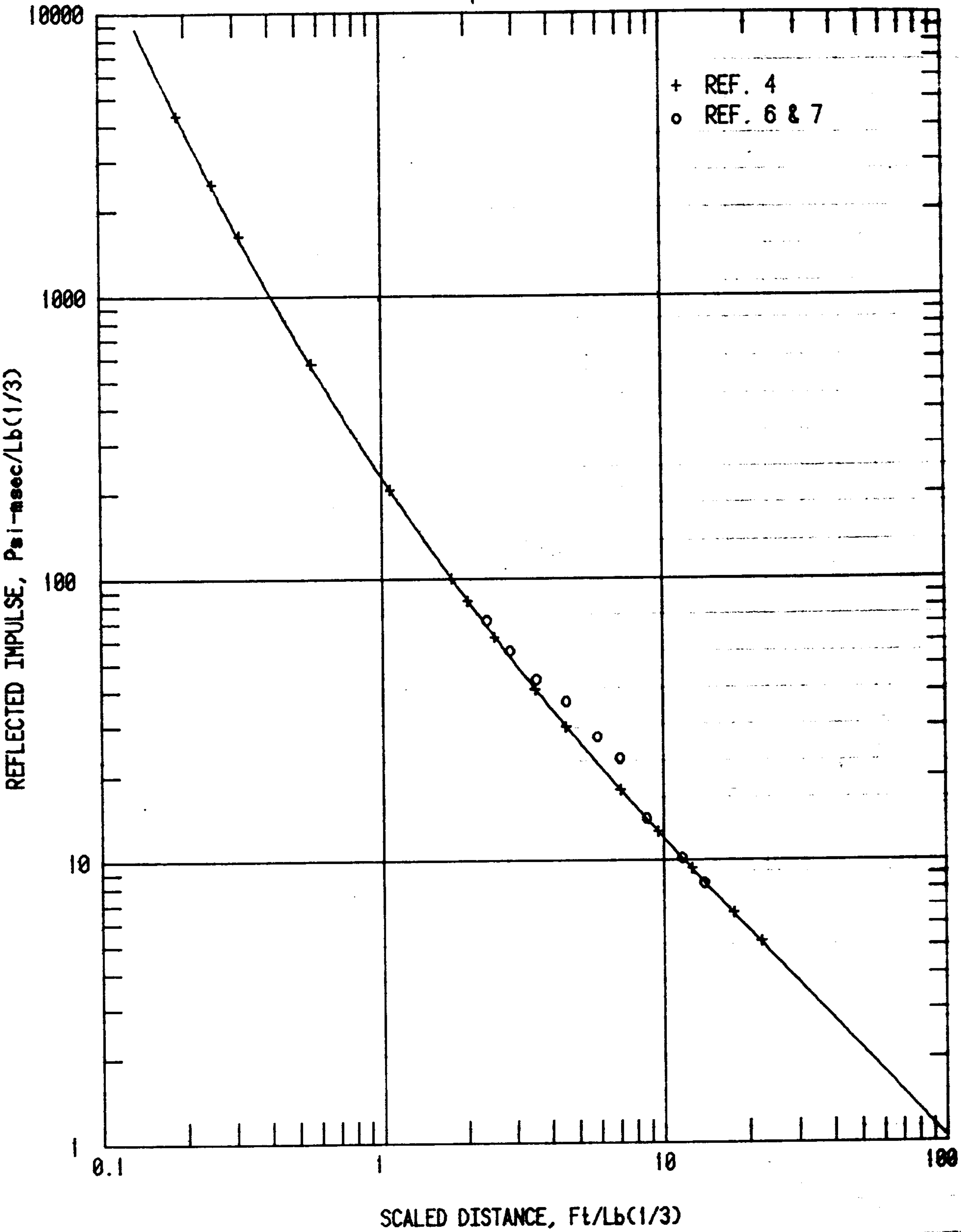


SCALED DISTANCE, Ft/Lb^(1/3)

TITLE Comparison of Revised Functional Approximation with Sources BOOK NO.______

From Page No.___

Attachment #64



Work continued 12/23/82 C Balmer

To Page No.

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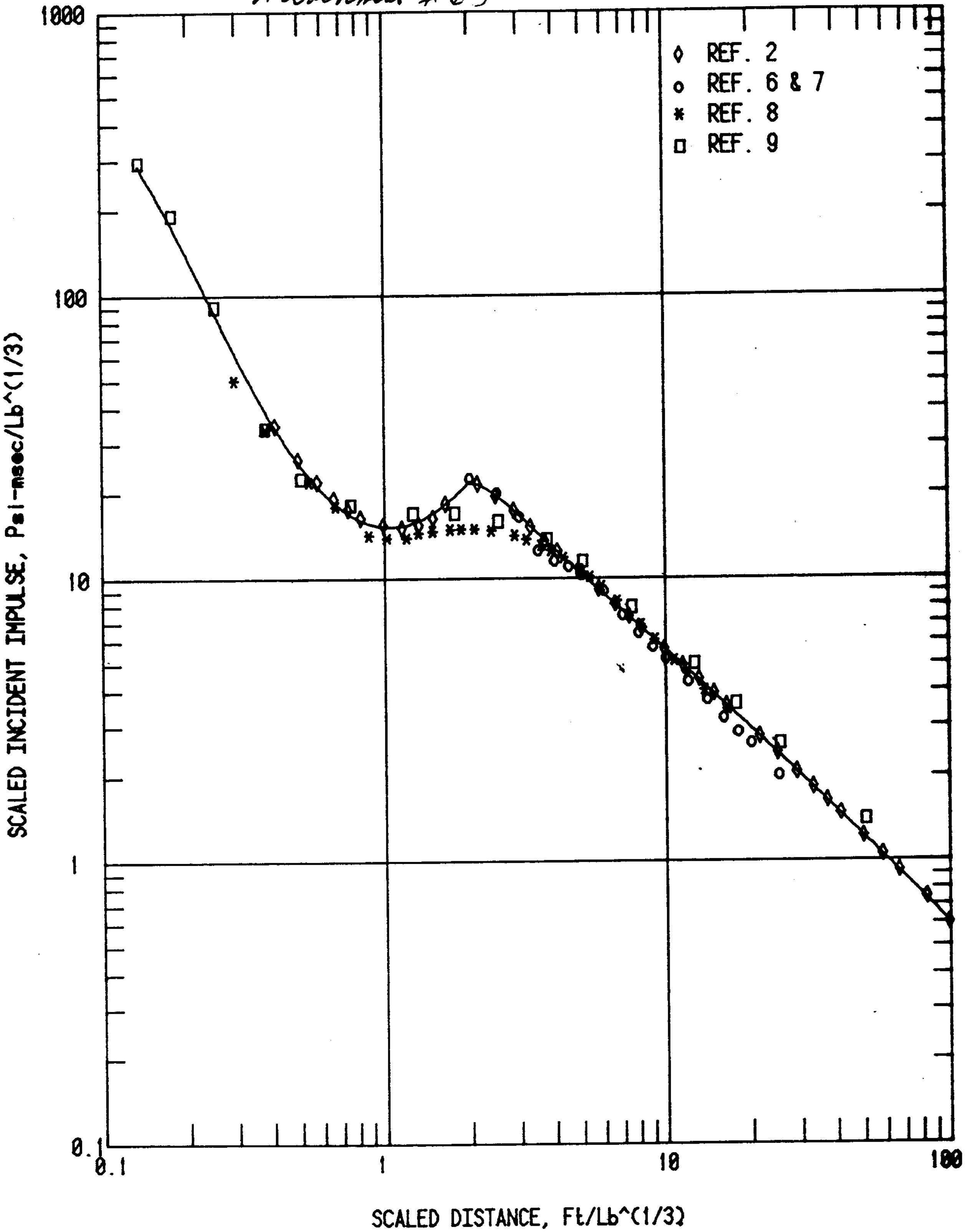
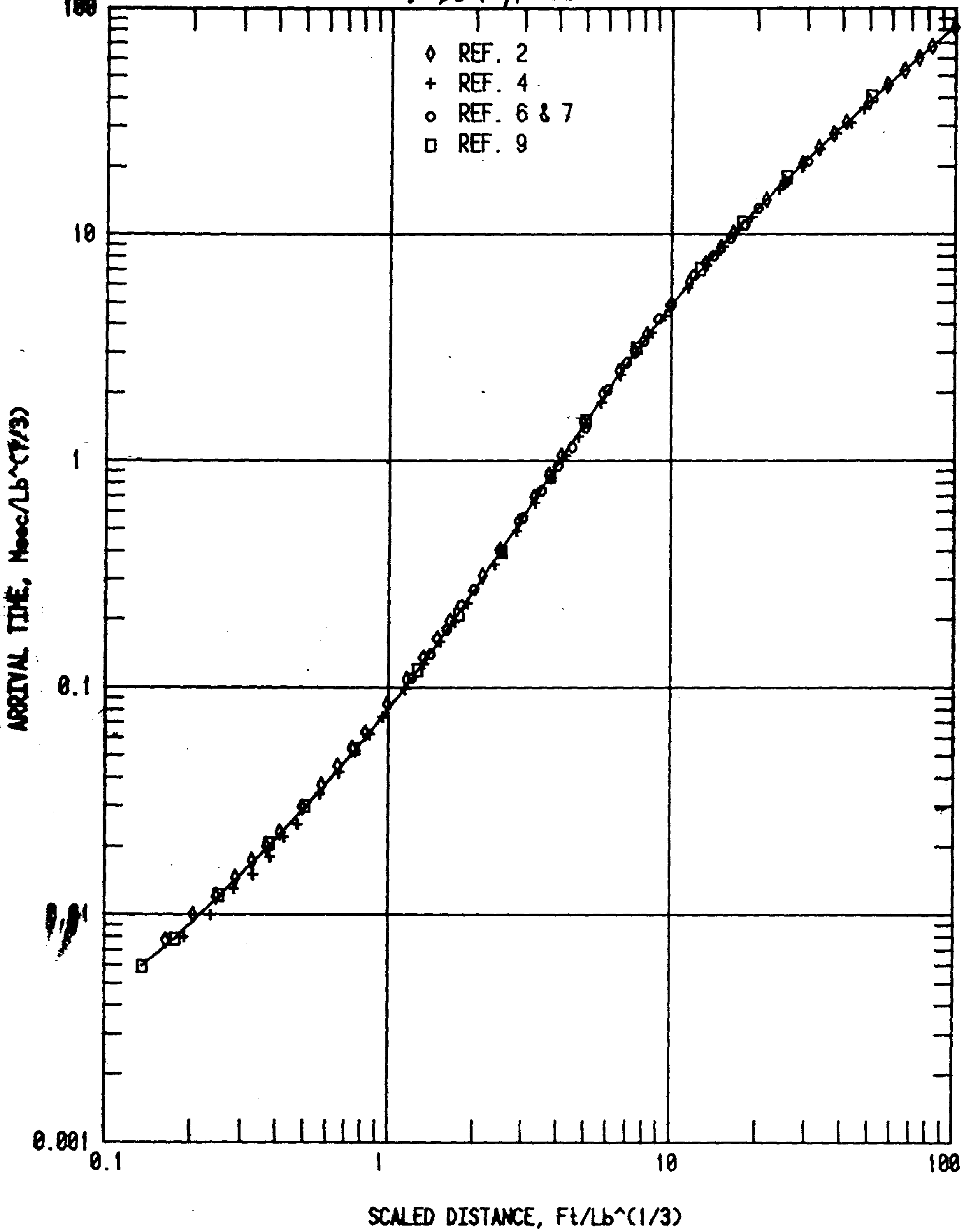
Attachment #63



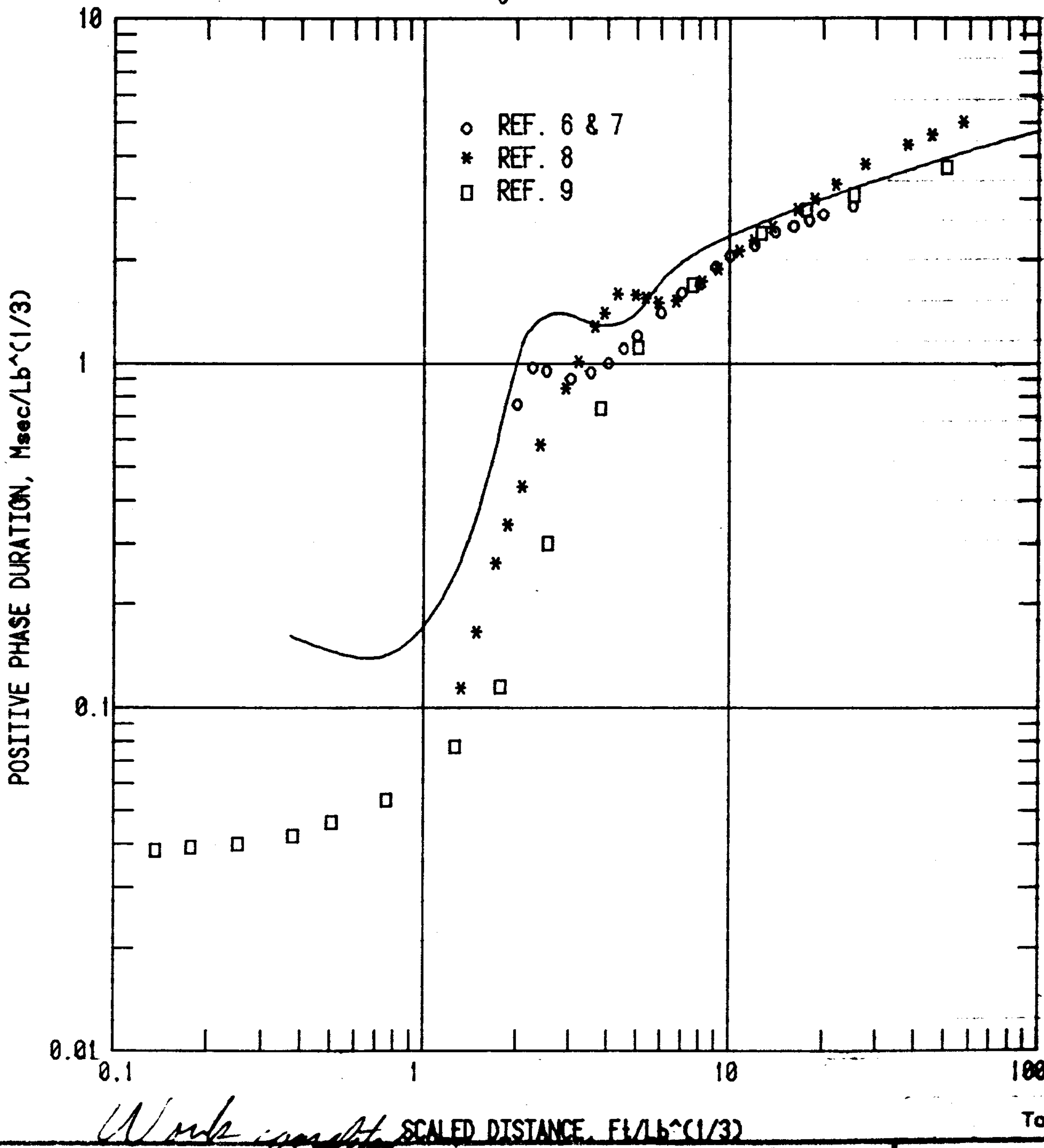
Attachment # 65



From Page No. 51

Attachment (opposite) #66 is a further revision of attachment #64 (page 51). This includes another reference: Ref. 5, Dept. of Energy. Further, ref 4 has been deleted since this is the source of the curve. Therefore its inclusion was superfluous. Attachment #67 (below) shows a comparison of sources for free air positive phase duration. The curve was generated by scaling surface burst data for duration. See page 33.

Attachment #67



Work completed

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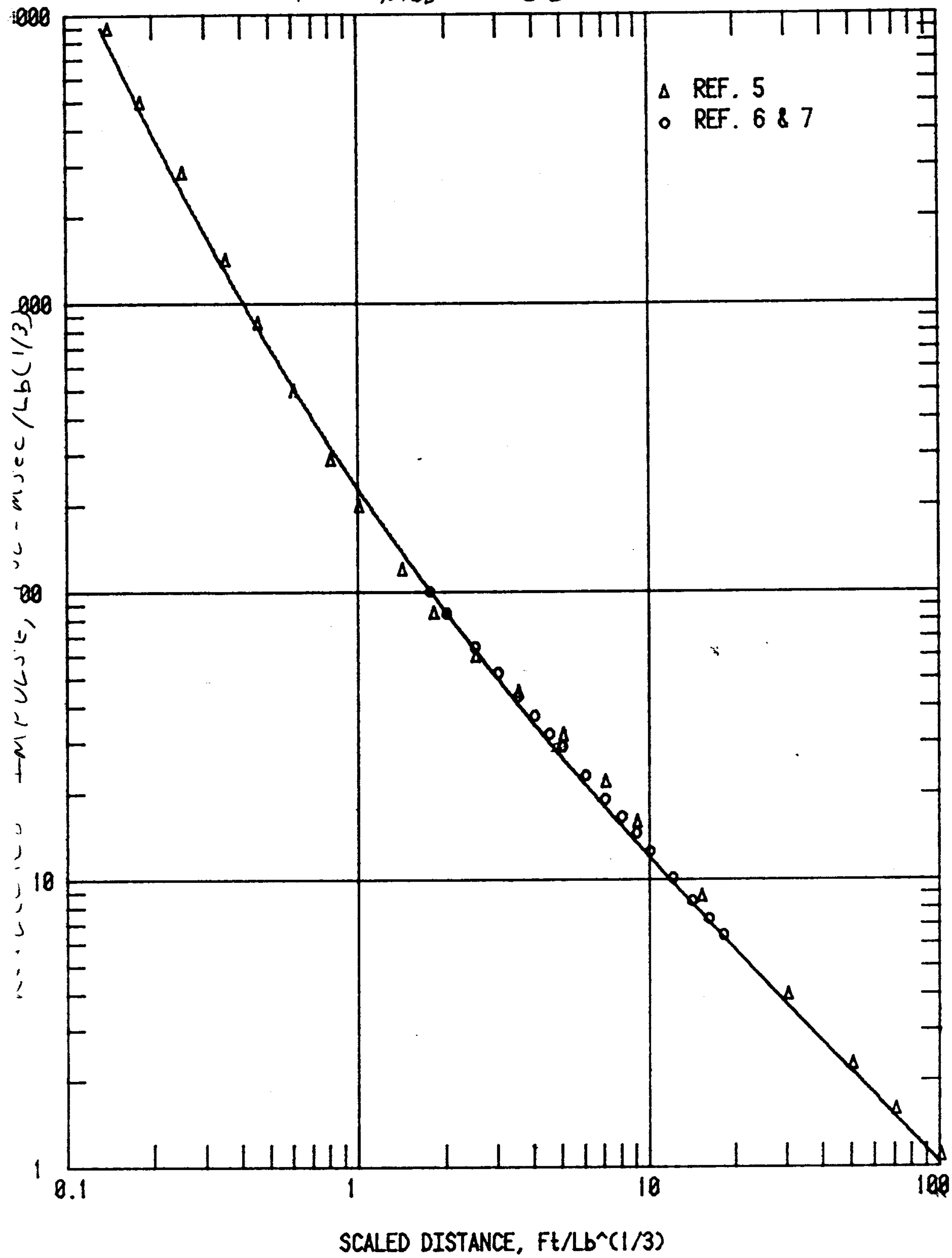
Attachment #66



From Page No.__

Functional representations to date are for blast parameters in English units and are scaled to a 1 LB TNT charge as a function of distance in feet. The metric representation must be for a 1 kilogram charge as a function of distance in meters.

Conversion factors:

1 pound = 0.453592 Kilograms
$1 \text{ pound}^{1/3} = 0.768343 \text{ Kilogram}^{1/3}$

1) $\frac{Ft}{LB^{1/3}} * \frac{0.3048 \text{ meter}}{0.768343 \text{ Kg}^{1/3}} = \boxed{0.396698} = m/Kg^{1/3}$

2) $\frac{msec}{LB^{1/3}} * \frac{1 \text{ msec}}{0.768343 \text{ Kg}^{1/3}} = \boxed{1.30150 = msec/Kg^{1/3}}$

3) $\frac{Psi\text{-}msec}{LB^{1/3}} * \frac{6.894757 \text{ Kpa-msec}}{0.768343 \text{ Kg}^{1/3}} = \boxed{8.97354} \frac{Kpa\text{-}msec}{Kg^{1/3}}$

4) $\frac{Ft}{msec} * \boxed{0.3048} \frac{M}{msec} = \frac{m}{msec}$

5) $Psi * 6.894757 = Kpa$

Multiply english units by the conversion factor in box to obtain metric units

Work continued 2/11/83 G Balunh

To Page No. 55

To convert distance use 1,

for pressure use 5, for impulse 3,

for duration and arrival time use 2, and

for shock front velocity use 4

Metric representation by functions developed as follows:

Convert input arrays to metric units.
Use Tektronix plot 50 software to generate polynomial regression functions of the same degree as their English counterparts.

The metric and English functional representations are identical except for the constant terms coefficients and very small computer round-off errors.

If T = common log of distance in English units
$U = K_0 + K_1 T$
Y = common log of the appropriate blast parameter

$$Y = C_0 + C_1 U + C_2 U^2 + \ldots C_n U^n$$

Then only K_0 and C_0 are changed by converting to metric units.

Work completed 2/11/83 CBulmash

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TITLE Comparison of Reflected Impulse Book No.

From Page No. Attachment #76 (opposite) shows comparison of BRL's I_r curve (solid line) for one lb TNT with data provided by Dr. Baker of the Southwest Research Institute. Dr. Baker thought I_r might be a little higher than that suggested by BRL. He said I_r close to the charge would be proportional to $1/R$ where R is the distance from the charge. Using a constant TNT equivalency factor of 1.17 I scaled the distance and impulse from Pentolite to TNT and, as can be seen from the plot, BRL and Southwest are actually using I_r data values that are virtually identical close to the charge.

Work completed 4/29/83 G Bulmash

To Page No.

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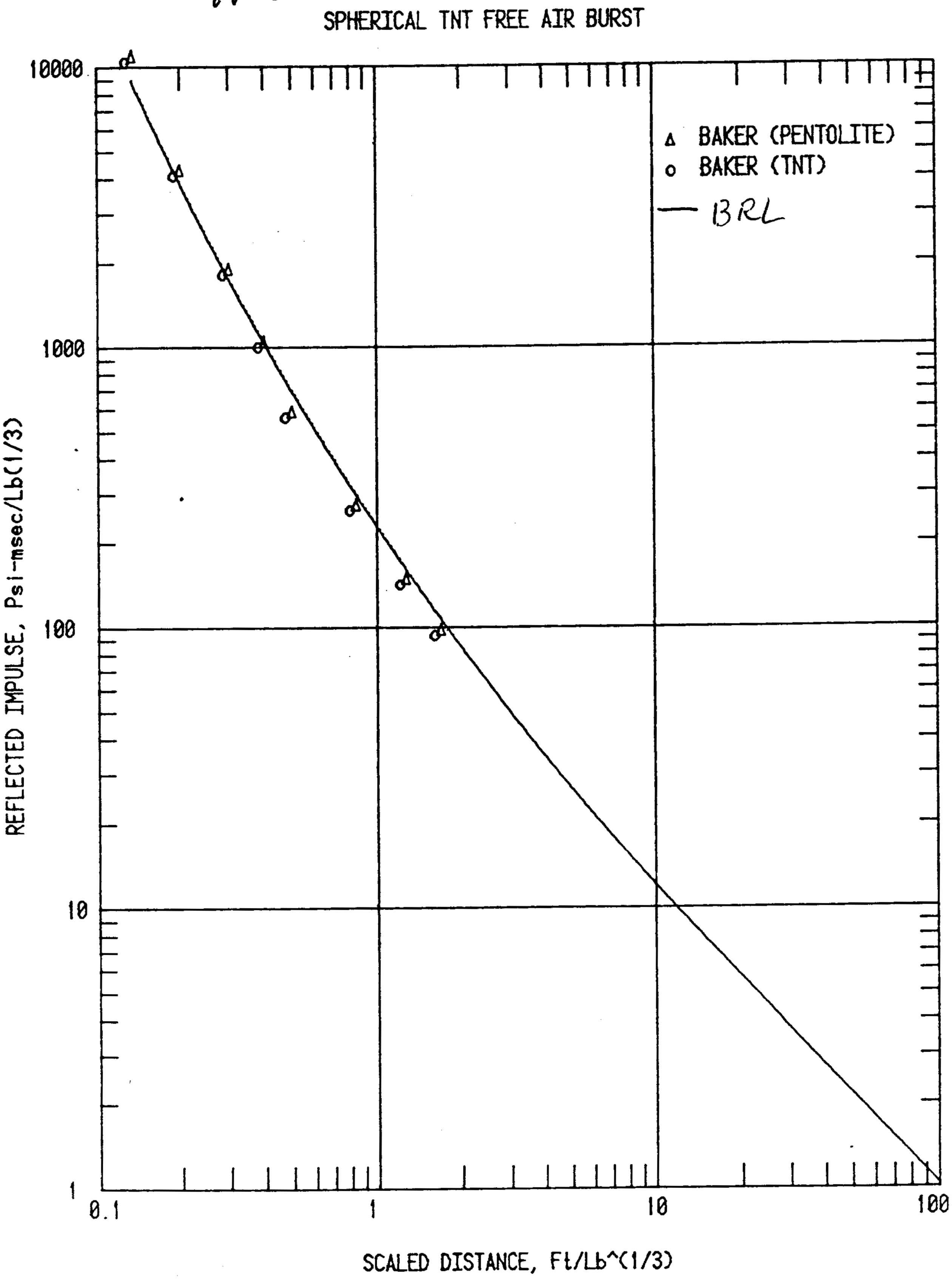
		Recorded by	

Attachment # 76



Project No.____
TITLE Comparison of Reflected Pressure Book No.____

From Page No.__ Attachment #77 (opposite) shows comparison of the BRL reflected pressure curve generated by the polynomial fit with several other sources

Ref 4 is Goodman's pentolite data
Ref 6+7 are Canadian HOB series
Ref 8 is NSWC
Ref 11 is Kingery's Parameter study, report #1249.
Ref 14 is Jack and Armendt "Measurements of Normally reflected shock parameters from explosive charges under simulated high altitude conditions"

Work completed 5/27/83 G Bulmash

To Page No.__

Witnessed & Understood by me.	Date	Invented by	Date
		Recorded by	

Attachment #77