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WHITE OAK LABORATORY

EXPLOSION EFFECTS AND PROPERTIES
PART I - EXPLOSION EFFECTS IN AIR

6 OCTOBER 1975

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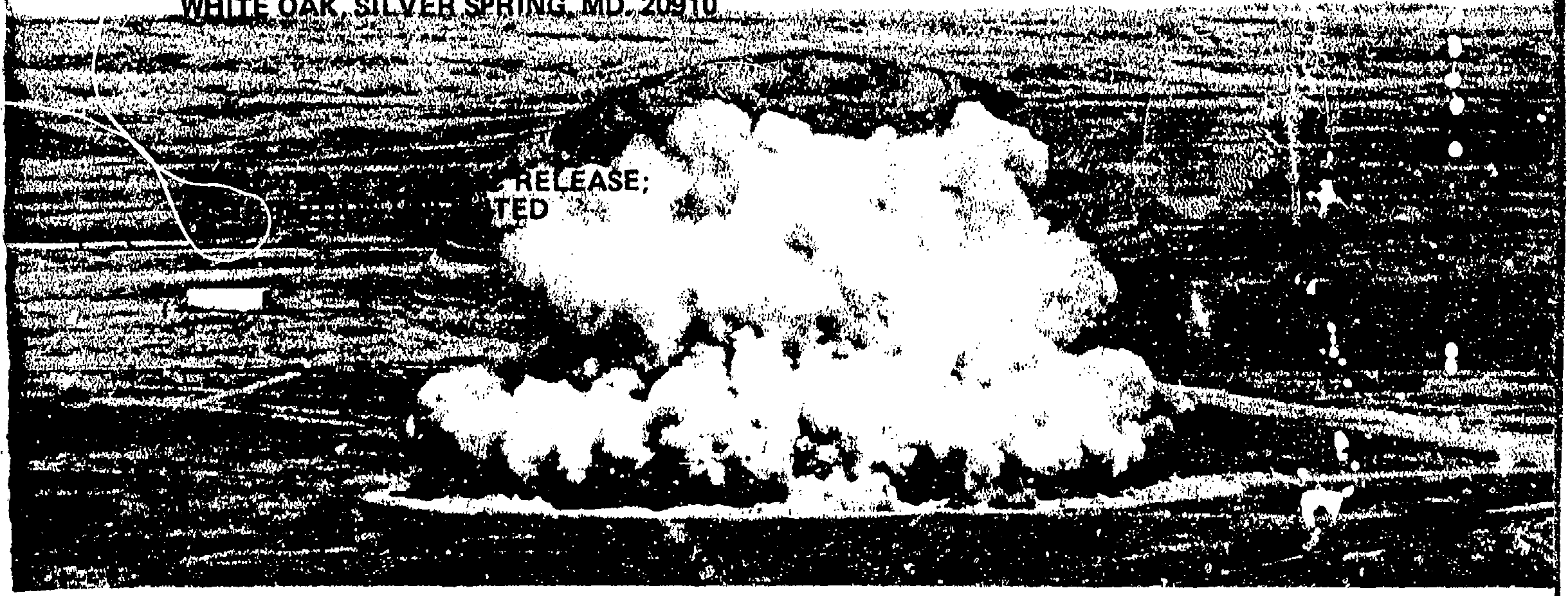

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This report updates and, therefore, supersedes Section A of an earlier report, NOLTR 65-218. The charts and graphs contained herein show the effects of explosives detonated both in the air and on and below the surface of the ground. Future reports will be issued to update Sections B, C, and D (Explosions in Water, Fragmentation, and Explosive Effects and Properties) of NOLTR 65-218.

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EXPLOSION EFFECTS AND PROPERTIES: PART I - EXPLOSION EFFECTS IN AIR

This report includes a new collection and presentation of existing data. It supersedes Section A (Explosions in Air) of NOLTR 65-218, "Explosives - Effects and Properties." Sections B, C, and D of NOLTR 65-218 will be superseded in forthcoming reports. In a report of this nature, errors are bound to creep in; the Center would appreciate having such errors brought to its attention, so that subsequent editions of this report can be more accurate. Please address correspondence to Commander, Naval Surface Weapons Center, White Oak, Silver Spring, Maryland 20910, Attention: Code WR-15.

This compilation was accomplished under Naval Sea Systems Command Task Number SF33-354-315/18460.

J.W. Enig

J. W. ENIG
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ILLUSTRATIONS

CHAPTER 1

EXPLOSION EFFECTS IN AIR

One of the major regions of energy release of an explosion taking place in air (or under a surface at small depths of burst) is the airblast. The explosion initially creates a relatively compact volume of high energy gases. The outward expansion of these gases produces a pressure (shock) wave which travels initially at supersonic speeds.

Under ideal conditions for a spherical charge, the front of the shockwave forms a sphere, centered at the site of the explosion. Immediately behind the front is a region of high velocity, high temperature air flow. At the shock front, the pressure, temperature, and density rise very suddenly to values much greater than that in the ambient atmosphere, and then decay to values lower than ambient conditions, with a reversal in the direction of the air flow. Eventually, these parameters return to the ambient conditions. These conditions are shown qualitatively in Figure 1a for three times--t_1, t_2, t_3, with $t_1 < t_2 < t_3$. Figure 1b is a redrawing of one of the pressure-time curves shown. On it are shown and defined some of the parameters of particular interest in airblast, namely: (1) time of arrival, (2) peak overpressure, (3) positive phase duration (positive duration), and (4) positive phase impulse (positive impulse).

Scaling laws are used to calculate the characteristic properties of the blast wave from an explosion of any given energy if those for another energy are known. With the aid of such laws, it is possible to present data for a large range of weights in a simple form.

Theoretically, a given pressure will occur at a distance from an explosion that is proportional to the cube-root of the energy yield (this is known as "cube-root scaling" or Hopkinson Scaling). Tests of Hopkinson Scaling have shown that it holds over a wide range of explosive weights (from microtons of explosive up to and including megatons). According to Hopkinson Scaling, if R_1 is the distance from a reference explosion of W_1 pounds at which a specified parameter occurs, such as overpressure or dynamic pressure (dynamic pressure, q, is $1/2\ \rho u^2$, where ρ is the density of air and u is the particle velocity), then for any explosion of W pounds, these same parameters will occur at a distance R given by:

$$R/R_1 = (W/W_1)^{1/3} \qquad (1)$$

Applying these same relationships to times and to impulses gives the following relationships:

$$t/t_1 = R/R_1 = (W/W_1)^{1/3} \qquad (2)$$

$$I/I_1 = R/R_1 = (W/W_1)^{1/3} \qquad (3)$$

where t_1 represents the arrival time or positive phase duration and I_1 is the positive impulse for the reference explosion of weight W_1; as before R and R_1 are distances from the new and reference charges.

By rearranging equations (1), (2), and (3), the following relationships are obtained:

$$R/W^{1/3} = R_1/W_1^{1/3} = \lambda \qquad (4)$$

$$t/W^{1/3} = t_1/W_1^{1/3} \text{ when } R/W^{1/3} = \frac{R_1}{W_1^{1/3}} \qquad (5)$$

$$I/W^{1/3} = I_1/W_1^{1/3} \text{ when } R/W^{1/3} = \frac{R_1}{W_1^{1/3}} \qquad (6)$$

The quantity $R/W^{1/3}$ is defined as the scaled distance, λ. The quantity $t/W^{1/3}$ is defined as scaled time, and $I/W^{1/3}$ as scaled positive impulse, where R, t, and I are the unscaled parameters.

All of the information presented in this report is based either on experimental data or computer extrapolations of experimental data. As with any result based on experimental data, there is an inherent scatter involved; i.e., the curves and tables presented represent the "best fit" or average values of the data, with some associated error band.

CAVEAT: These scaling laws are strictly applicable only under certain conditions; namely:

(1) identical ambient conditions
(2) identical charge shapes
(3) identical charge to surface geometries

however, for practical reasons, they are applied even when only similar conditions exist.

Most of the information presented in this report is in terms of English units of measure. Figure 1c contains conversion factors for converting this information to the Metric System.

A list of symbols used in this report are defined and presented in Figure 1d. Figure 1e presents a graph of cube roots of numbers up to 10^6.

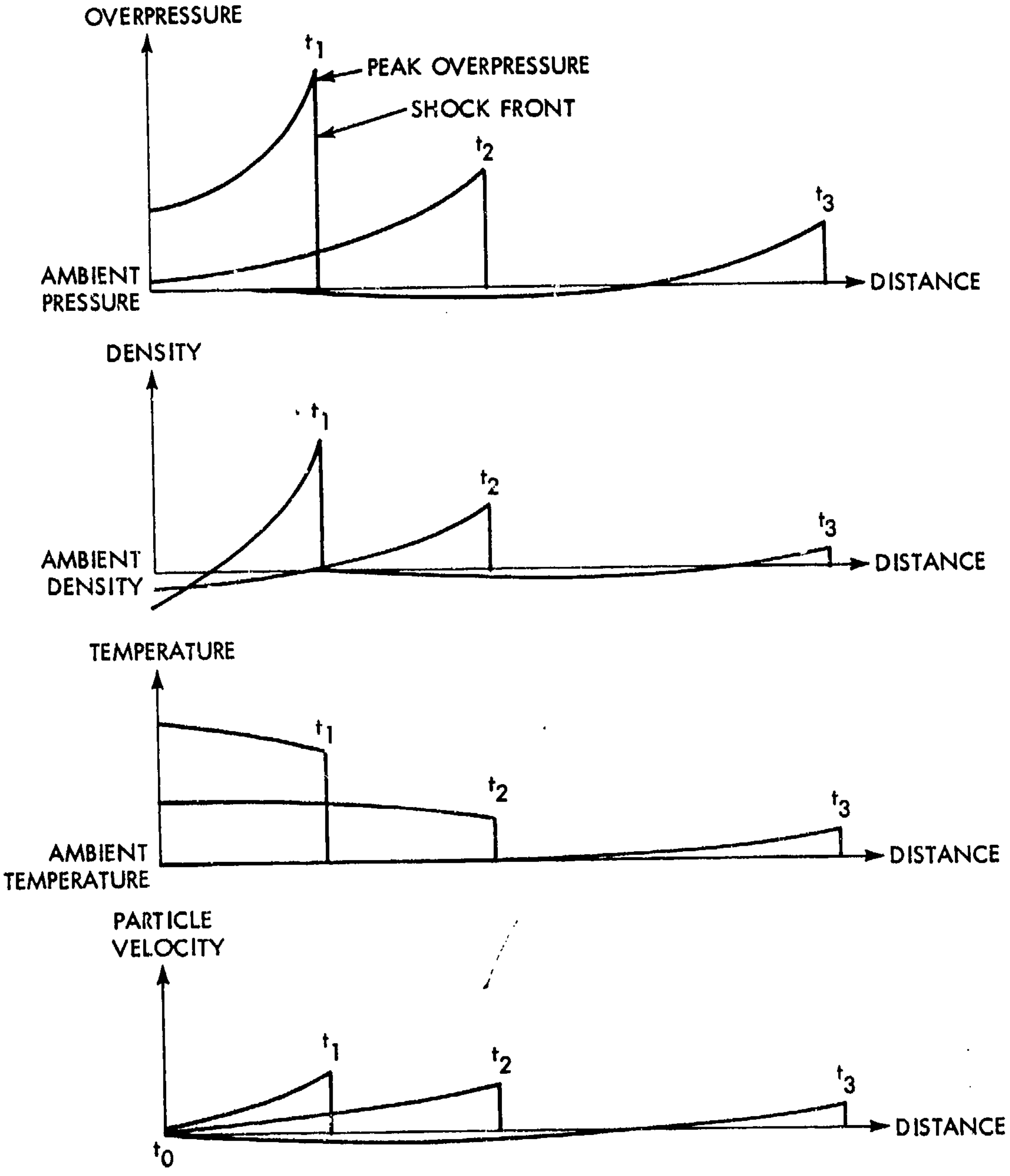
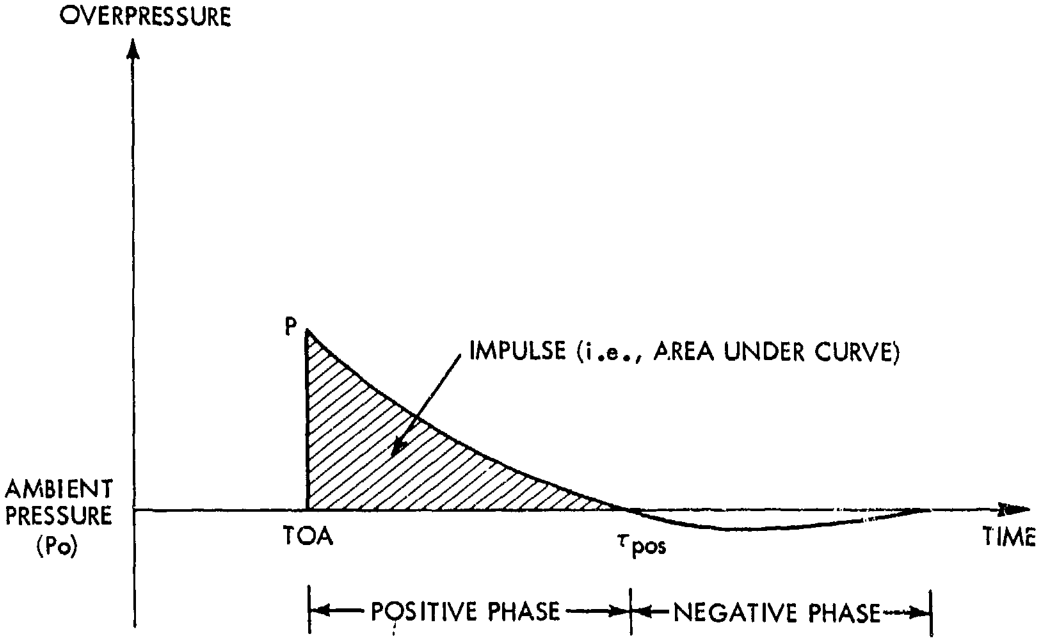


FIG. 1a QUALITATIVE VARIATION OF SHOCK WAVE PARAMETERS WITH DISTANCE AND TIME



(1) TOA (TIME-OF-ARRIVAL) = THE TIME REQUIRED FOR THE SHOCK WAVE TO TRANSIT THE DISTANCE FROM THE CENTER OF THE EXPLOSION TO THE POINT AT WHICH THE MEASUREMENT IS TO BE MADE.

(2) P (OVERPRESSURE) = PEAK PRESSURE ABOVE AMBIENT CONDITIONS.

(3) τ = POSITIVE PHASE DURATION - THE LENGTH OF TIME (MEASURED FROM THE FIRST PRESSURE RISE) NECESSARY FOR THE OVERPRESSURE TO RETURN TO THE AMBIENT PRESSURE.

(4) POSITIVE PHASE IMPULSE = $\int_0^\tau P(t)\,dt$

FIG. 1b IMPORTANT SHOCK WAVE PARAMETERS

TO CONVERT	INTO	MULTIPLY BY
FEET	CENTIMETERS	30.48
FEET	METERS	0.3048
METERS	FEET	3.281
CENTIMETERS	FEET	3.281×10^{-2}
CUBIC FEET	CUBIC CMS.	28320
CUBIC FEET	CUBIC METERS	2.832×10^{-2}
CUBIC CMS.	CUBIC FEET	3.531×10^{-5}
CUBIC METERS	CUBIC FEET	35.31
POUNDS	GRAMS	453.59
POUNDS	KILOGRAMS	0.4536
GRAMS	POUNDS	2.205×10^{-3}
KILOGRAMS	POUNDS	2.205
TONS (SHORT)	POUNDS	2000
TONS (SHORT)	KILOGRAMS	907.185
GRAMS/CM^3	POUNDS/IN^3	3.613×10^{-2}
GRAMS/CM^3	POUNDS/FT^3	62.43
POUNDS/IN^3	GRAMS/CM^3	27.68
POUNDS/FT^3	GRAMS/CM^3	1.602×10^{-2}
KG/M^3	POUNDS/FT^3	6.243×10^{-2}
POUNDS/FT^3	KG/M^3	16.02
PSI(POUNDS PER SQUARE INCH)	BARS	6.895×10^{-2}
BARS	PSI	14.504
PSI (POUNDS PER SQUARE INCH)	PASCALS (NEWTON/M^2)	6.897×10^{3}
PASCALS	PSI	1.45×10^{-4}
PSI	DYNES/CM^2	6.895×10^{4}
PSI - MSEC	BAR - MSEC	6.895×10^{-2}
FT/LB$^{1/3}$	METERS/KG$^{1/3}$	0.3967

FIG. 1c CONVERSION FACTORS

C_o	ambient speed of sound (ahead of shock front) (ft/sec); at 0^oC--1087 ft/sec
C	sound velocity at temperature t (^oC), ft/sec
d	charge depth, feet (for underwater bursts)
D	charge depth, feet (for underground bursts)
D_a	maximum depth of apparent crater below preshot ground surface, feet
H	burst height above terrain, feet
I	positive impulse, psi-msec
M	metal case weight of a cylindrical section of a cased explosive, pounds
P	peak overpressure at the shock front
P_o	ambient pressure ahead of the shock front; 14.7 psi at sea level
P_i	initial peak overpressure
P_r	reflected overpressure
q	dynamic pressure, psi
R	horizontal range from ground zero, feet
R_a	radius of apparent crater measured at preshot ground surface feet
SGZ	surface ground zero, point on surface vertically above or below burst point

FIG. 1d DEFINITION OF SYMBOLS

T	height of triple point above terrain, feet
t	temperature, ^{o}C
TOA	time of arrival, msec
u	particle velocity, ft/sec
U	shock velocity, ft/sec
V	chamber volume, cubic feet
V_a	volume of apparent crater below preshot ground surface, cubic feet
W	weight of explosive, pounds
X	adjusted scaled ground range, $ft/(lb\ TNT)^{1/3}$
Y	vertical distance to measurement point
α	angle between blast wave front and reflecting surface
γ	ratio of the specific heats of air
λ	Hopkinson scaled distance, $ft/lb^{1/3}$
λ_d	scaled charge depth, $d/W^{1/3}$, $ft/lb^{1/3}$ (for underwater bursts)
λ_D	scaled charge depth, $D/W^{1/3}$ $(ft/lb^{1/3})$ (for underground bursts)
λ_X	scaled horizontal distance, $R/W^{1/3}$ $(ft/lb^{1/3})$
λ_Y	scaled vertical distance, $Y/W^{1/3}$ $(ft/lb^{1/3})$
λ_H	scaled height of burst, $H/W^{1/3}$ $(ft/lb^{1/3})$
λ_T	scaled height of triple point, $T/W^{1/3}$ $(ft/lb^{1/3})$
λ_{R_a}	scaled apparent crater radius, $R_a/W^{5/16}$, $ft/lb^{5/16}$
λ_{D_a}	scaled apparent crater depth, $D_a/W^{5/16}$, $ft/lb^{5/16}$

FIG. 1d DEFINITION OF SYMBOLS (Continued)

λ_{V_a}	scaled cube root of apparent crater volume, $V_a^{1/3}/W^{5/16}$, ft/lb$^{5/16}$
ρ	density of air behind shock front
ρ_0	density of air ahead of shock front
ρ/ρ_0	density ratio across shock front
ρ'	specific gravity of soil
τ	positive duration, msec

FIG. 1d DEFINITION OF SYMBOLS (Continued)

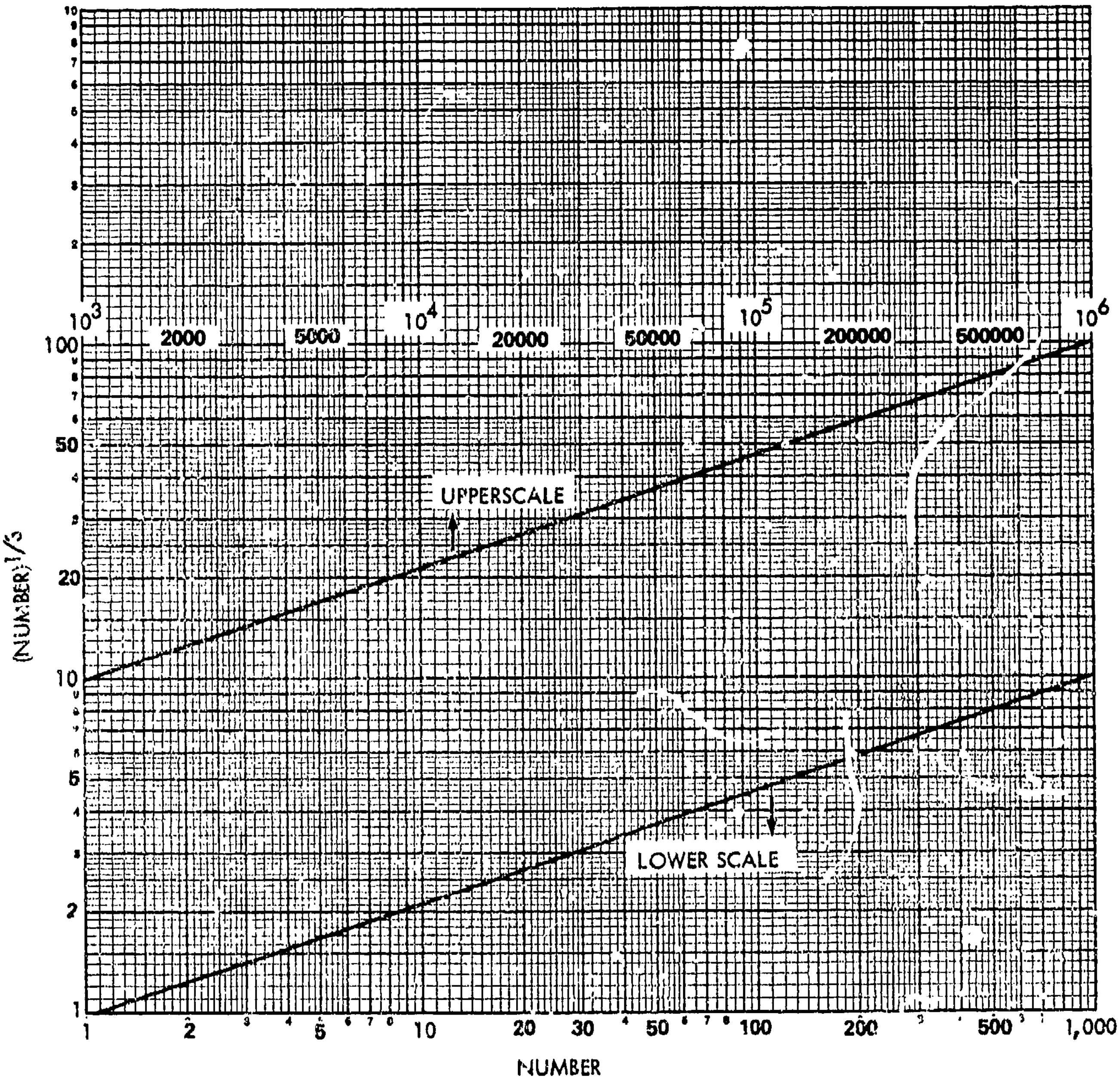


FIG. 1e CUBE ROOTS OF NUMBERS

CHAPTER 2

EQUIVALENT WEIGHT

The free air equivalent weight of a particular explosive is the weight of a standard explosive, e.g., TNT, required to produce a selected shock wave parameter of equal magnitude to that produced by a unit weight of the explosive in question. A given explosive may have several equivalent weights, depending on the shock wave parameter selected; i.e., it may have an equivalent weight based on peak overpressure, positive impulse, time of arrival, or positive duration. In general equivalent weights based either on time of arrival or positive duration are not available and must be approximated. Equivalent weight based on peak pressure can be used for the equivalent weight for time of arrival, and equivalent weight based on positive impulse can be used for that based on positive duration.

For valid comparisons, the test and standard explosives should have the same geometries, or consideration should be given to the effect of geometry on the comparison being made.

Strictly speaking, the equivalent weight of an explosive for any given blast parameter varies as a function of distance from the charge, i.e., the pressure-distance (or impulse-distance) curve for explosive X is not necessarily parallel to that of TNT. For many purposes, it is sufficient to cite a single equivalent weight number—the linear average of equivalent weights over some range of pressure. However, for other purposes it may be best to use the equivalency figure at the pressure level of concern. Both average numbers and plots are included in Figures 2a through 2j. Average values are obtained by calculating equivalent weight values at selected pressures throughout the data interval, and then taking a linear average. For example, over a 5-100 psi interval, the equivalent weights would be chosen at pressures of 5, 10, 15, psi, etc., and then averaged.

Problem Example 1

What weight of TNT is needed to produce the same over-pressure as 5 pounds of H-6 at a fixed distance?

Solution

(a) Figure 2i gives the equivalent weight for peak pressure of H-6 as 1.38 relative to TNT over the pressure range of 5-100 psi

(b) $\frac{1 \text{ lb H-6}}{5 \text{ lb H-6}} = \frac{1.38 \text{ lb TNT}}{X}$

(c) $X = (5)\ (1.38 \text{ lb of TNT}) = 6.90 \text{ lb of TNT}$

(d) 5 lb of H-6 = 6.90 lb of TNT

(e) To be more accurate, the pressure levels at which the comparisons are to be made would need to be specified and the equivalent weights read from curve 2e. For example, if the comparisons were to be made at 10 psi, 30 psi, and 80 psi, with 5 pounds of H-6:

at 10 psi, EW = 1.27

at 30 psi, EW = 1.305

at 80 psi, EW = 1.515

$X_{10} = (5)(1.27) = 6.35 \text{ lb of TNT}$

$X_{30} = (5)(1.305) = 6.525 \text{ lb of TNT}$

$X_{80} = (5)(1.515) = 7.575 \text{ lb of TNT}$

Problem Example 2

For a given pressure level, how much would the shock radius change if the explosive is changed from Tritonal to Composition C-4?

Solution

(a) For equal pressures, the equivalent TNT scaled distances should be the same

(b)
$$\lambda_{TNT/TRIT} = \frac{R_{TRIT}}{\left(W_{TRIT} \times EW_{TRIT/TNT}\right)^{1/3}}$$

$$\lambda_{TNT/C-4} = \frac{R_{C-4}}{\left(W_{C-4} \times EW_{C-4/TNT}\right)^{1/3}}$$

(c) From Figure 2i, the equivalent weight of tritonal and C-4 are 1.07 and 1.37 respectively:

or 1.07 lb TNT = 1 lb tritonal
and 1.37 lb TNT = 1 lb Composition C-4

(d) $$\lambda_{TNT/TRIT} = \frac{R_{TRIT}}{(1.07 \text{ lb TNT})^{1/3}}$$

$$\lambda_{TNT/TRIT} = \frac{R_{C-4}}{(1.37 \text{ lb TNT})^{1/3}}$$

(e) $\lambda_{TNT/TRIT} = \lambda_{TNT/C-4}$ for equal pressures

(f) $$\frac{R_{TRIT}}{R_{C-4}} = \left(\frac{1.07 \text{ lb TNT}}{1.37 \text{ lb TNT}}\right)^{1/3} = (.78)^{1/3} = .92$$

(g) $R_{C-4} = 1.09\ R_{TRIT}$ for a given pressure level

Reference

Maserjian, J. and Fisher, E., "Determination of Average Equivalent Weight and Average Equivalent Volume and their Precision Indexes for Comparison of Explosives in Air," NAVORD Report 2264, 2 November 1951

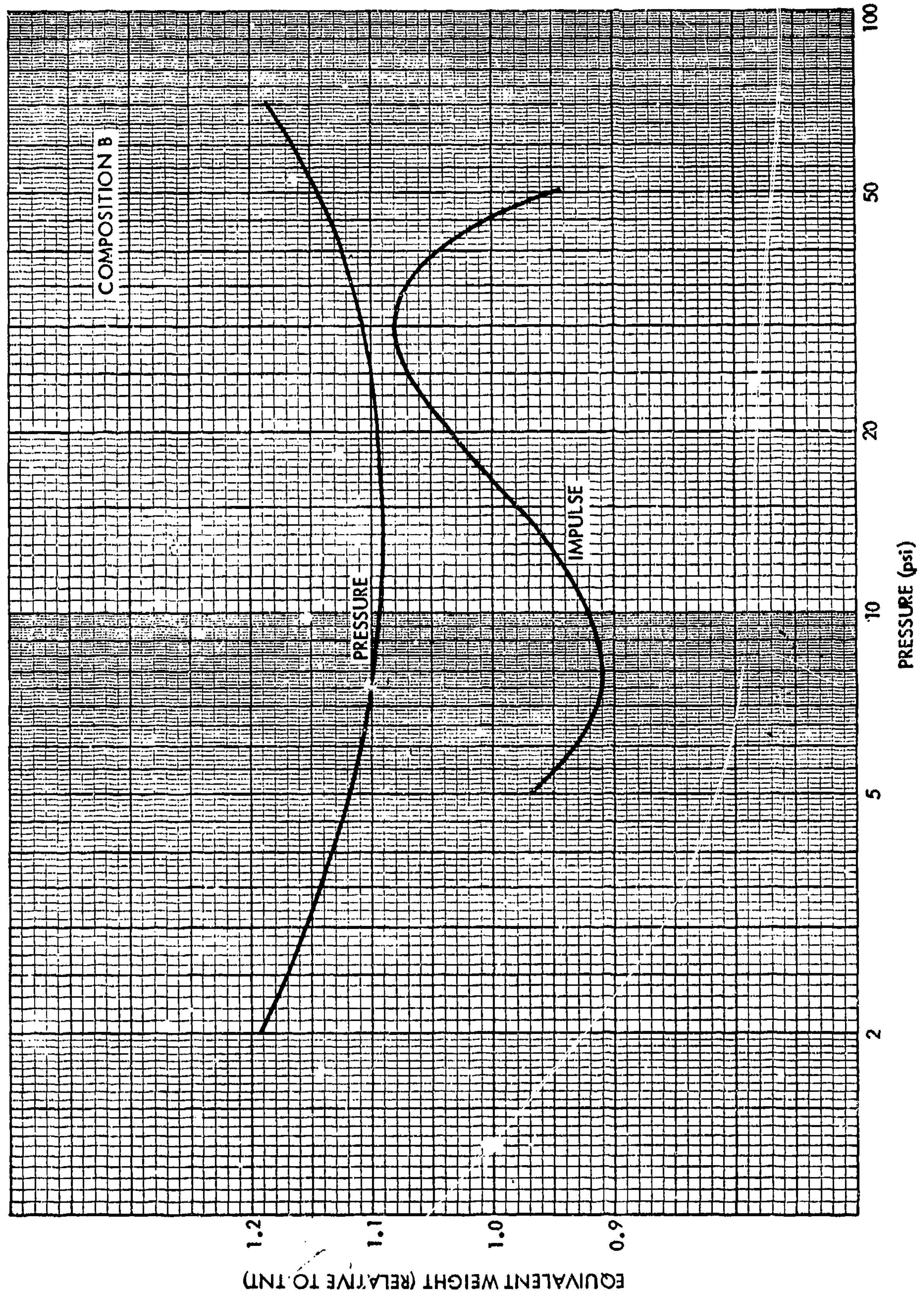


FIG. 2a FREE - AIR EQUIVALENT WEIGHT VS PEAK OVERPRESSURE FOR COMPOSITION B

(d) $$\lambda_{TNT/TRIT} = \frac{R_{TRIT}}{(1.07\ \text{lb TNT})^{1/3}}$$

$$\lambda_{TNT/TRIT} = \frac{R_{C-4}}{(1.37\ \text{lb TNT})^{1/3}}$$

(e) $\lambda_{TNT/TRIT} = \lambda_{TNT/C-4}$ for equal pressures

(f) $$\frac{R_{TRIT}}{R_{C-4}} = \left(\frac{1.07\ \text{lb TNT}}{1.37\ \text{lb TNT}}\right)^{1/3} = (.78)^{1/3} = .92$$

(g) $R_{C-4} = 1.09\ R_{TRIT}$ for a given pressure level

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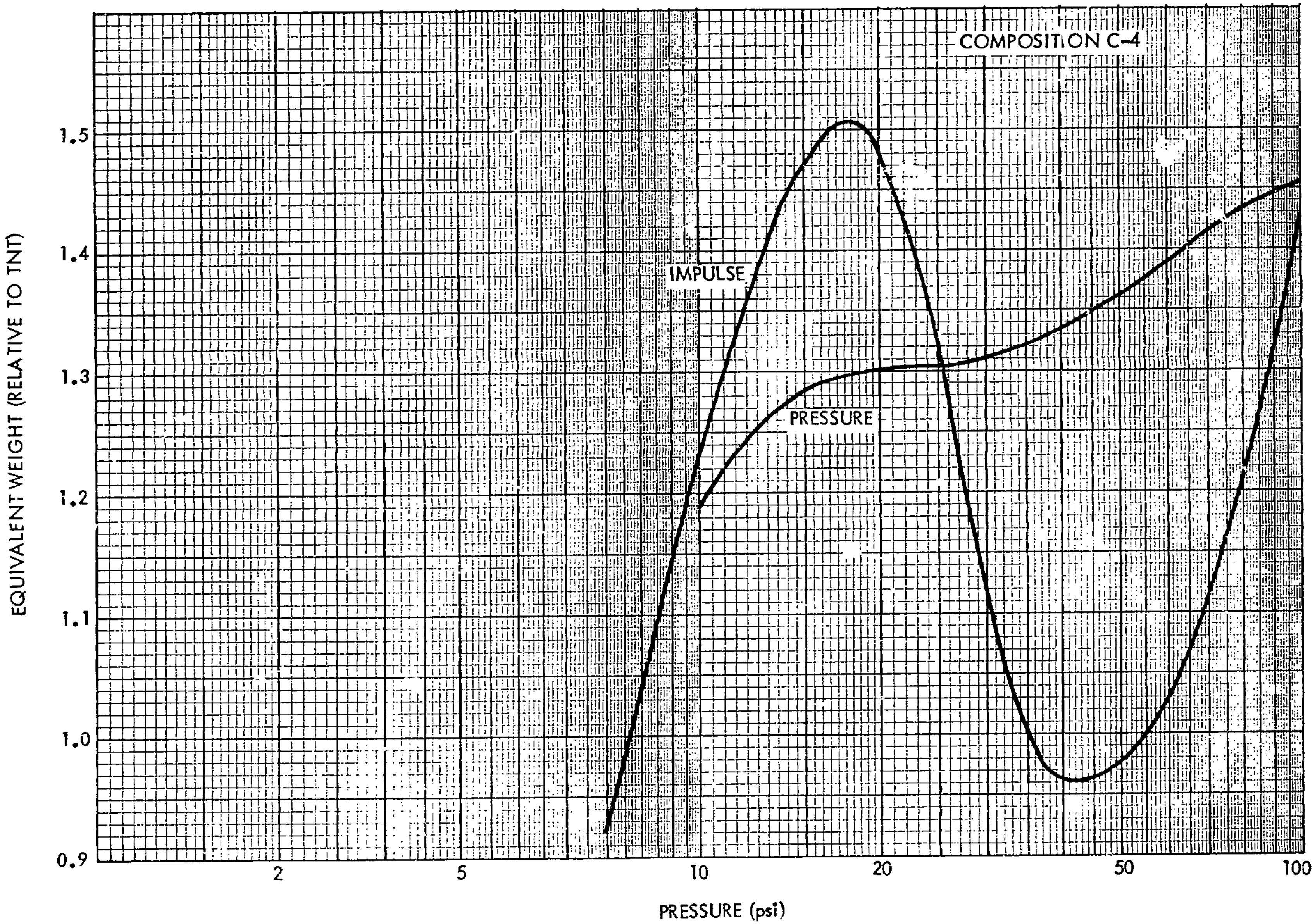

FIG. 2b FREE - AIR EQUIVALENT WEIGHT VS PEAK OVERPRESSURE FOR COMPOSITION C - 4

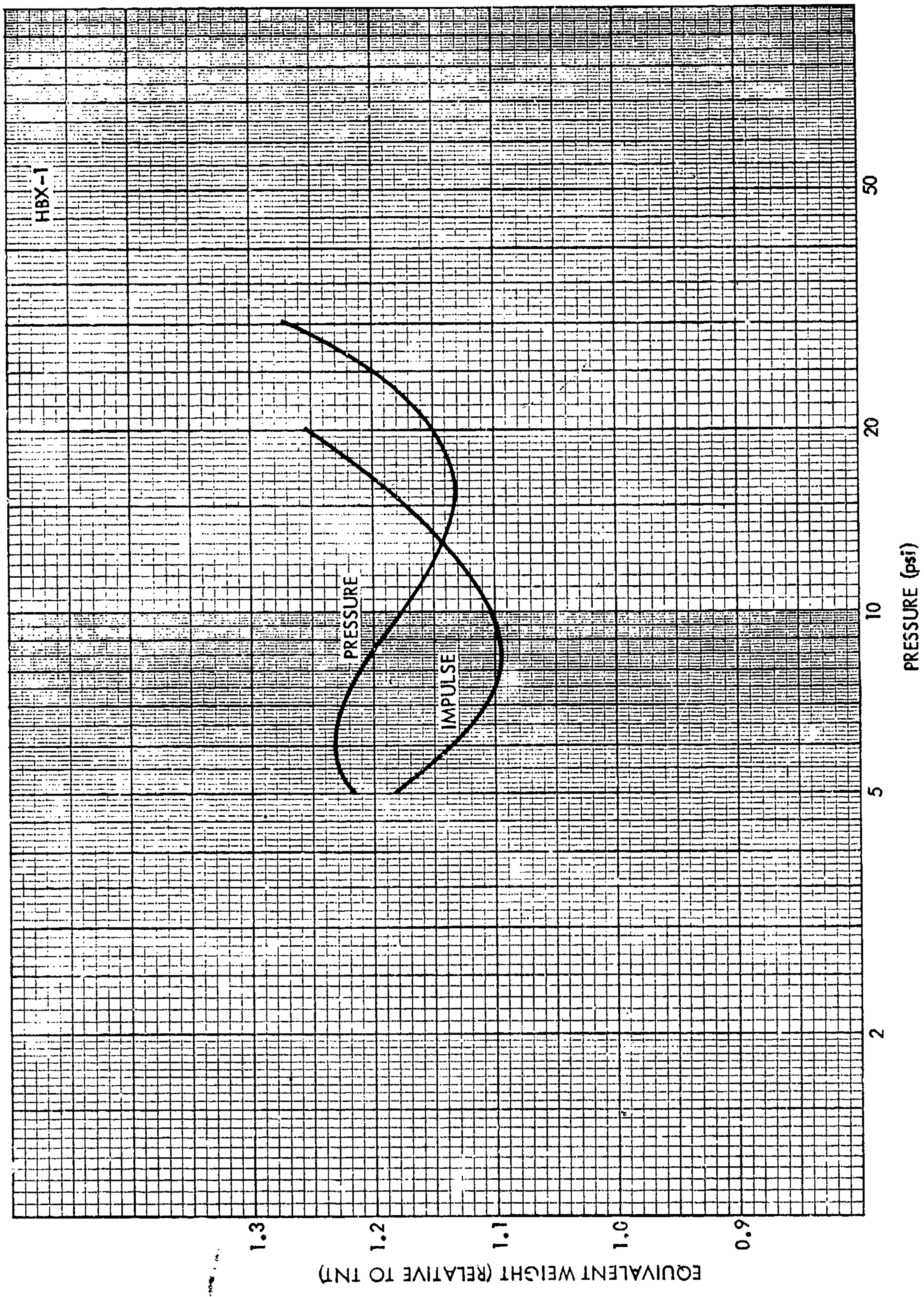

FIG. 2c FREE - AIR EQUIVALENT WEIGHT VS PEAK OVERPRESSURE FOR HBX - 1

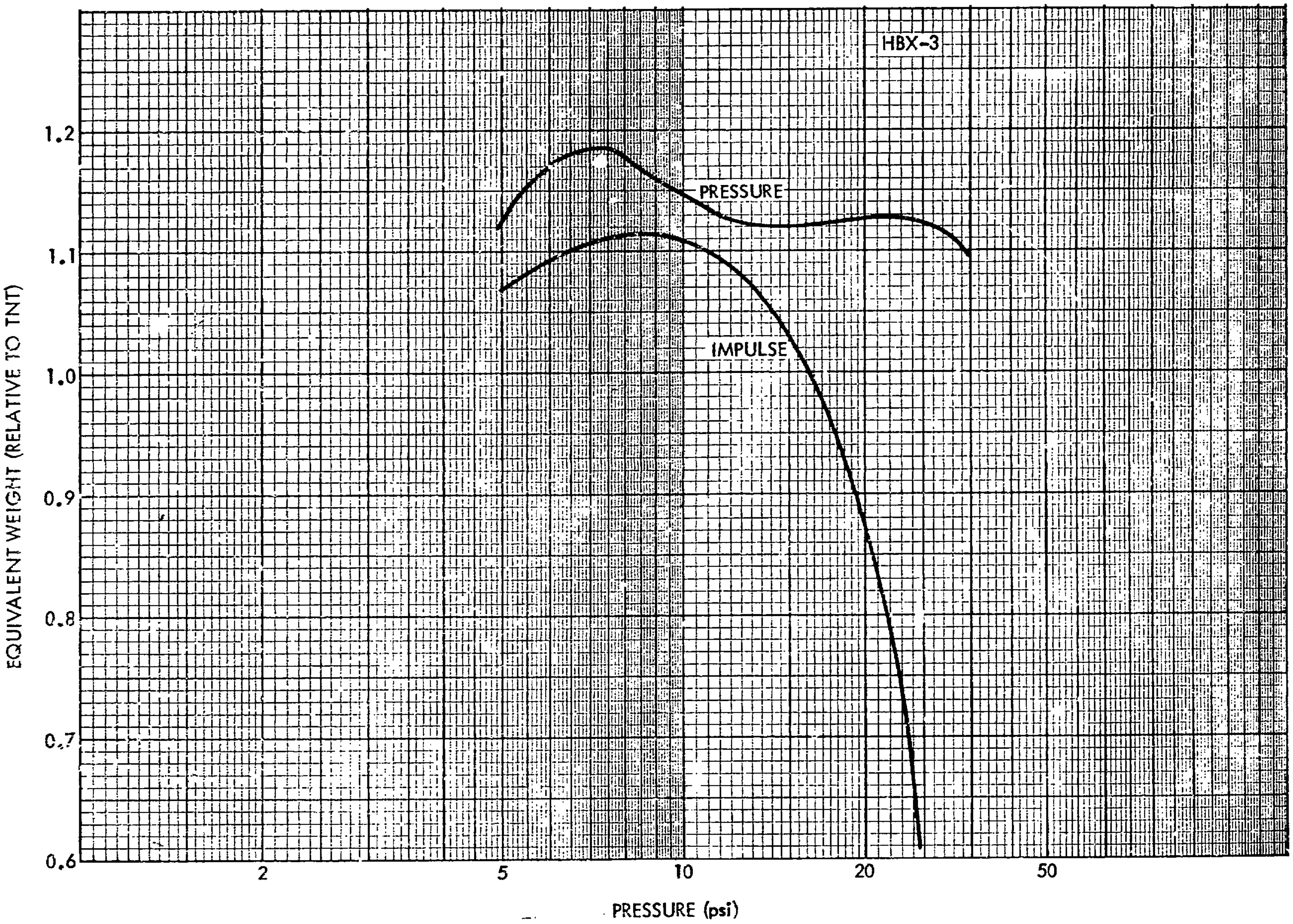

FIG. 2d FREE - AIR EQUIVALENT WEIGHT VS PEAK OVERPRESSURE FOR HBX - 3

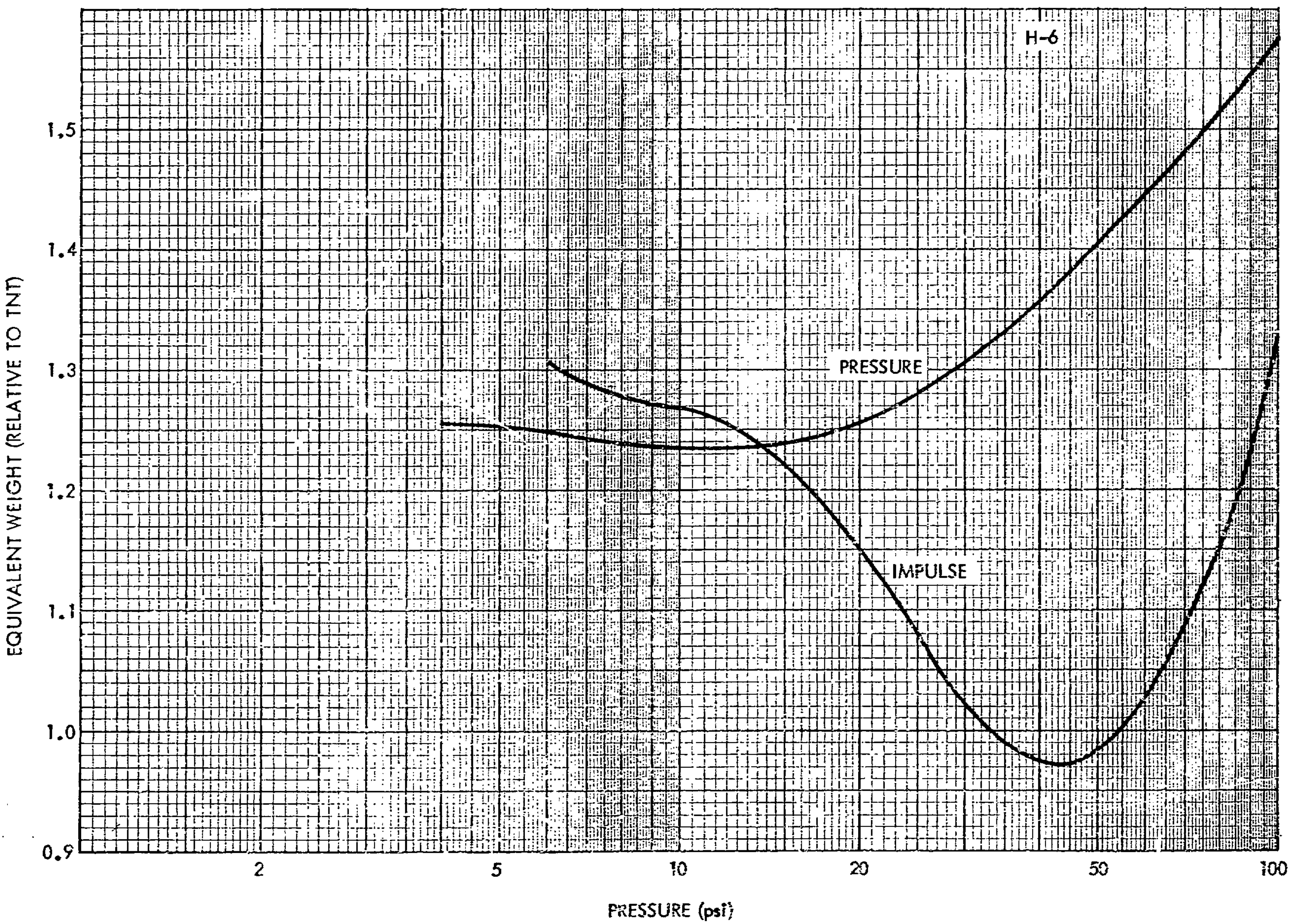

FIG. 2e FREE-AIR EQUIVALENT WEIGHT VS PEAK OVERPRESSURE FOR H – 6

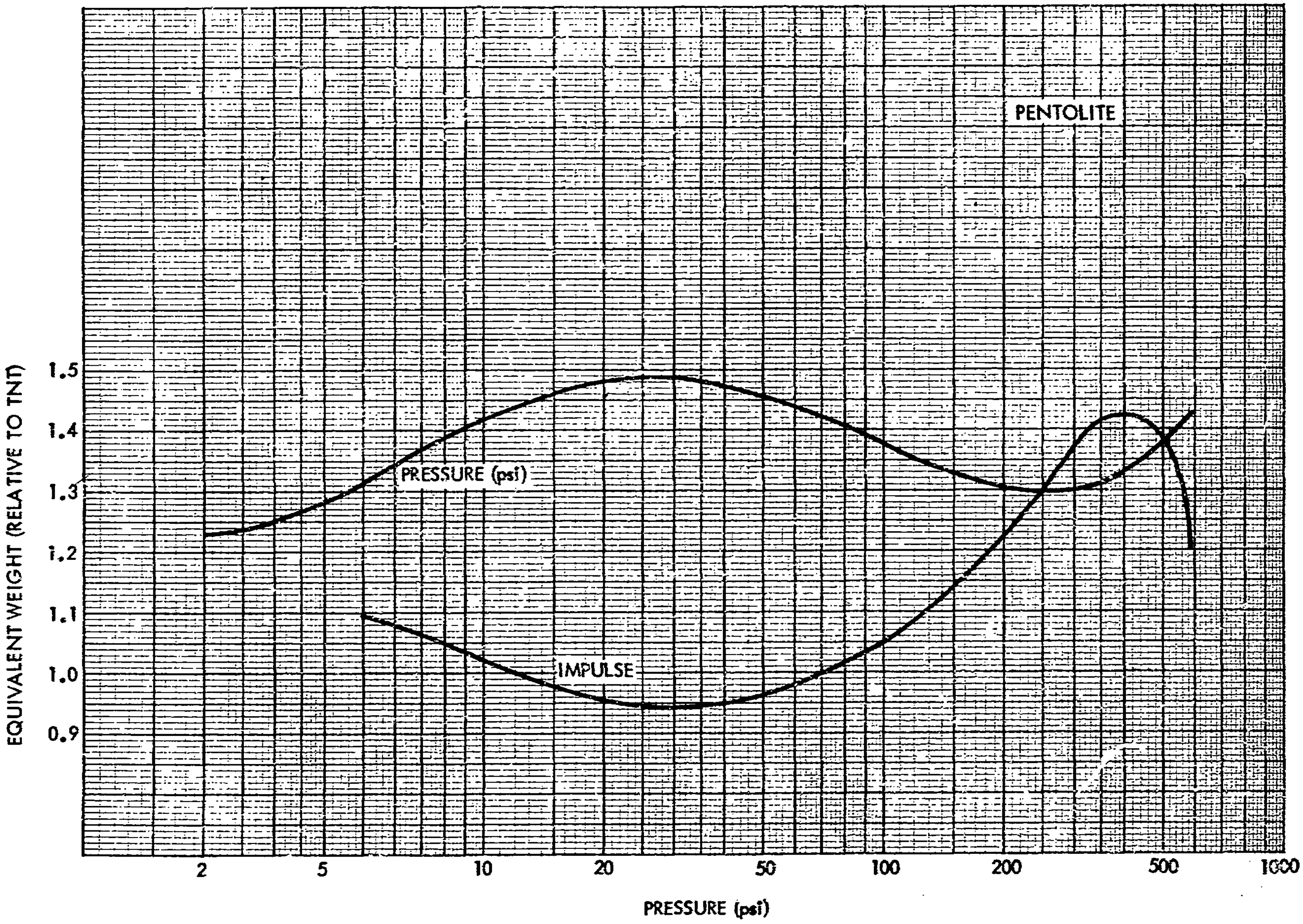

FIG. 2f FREE - AIR EQUIVALENT WEIGHT VS PEAK OVERPRESSURE FOR PENTOLITE

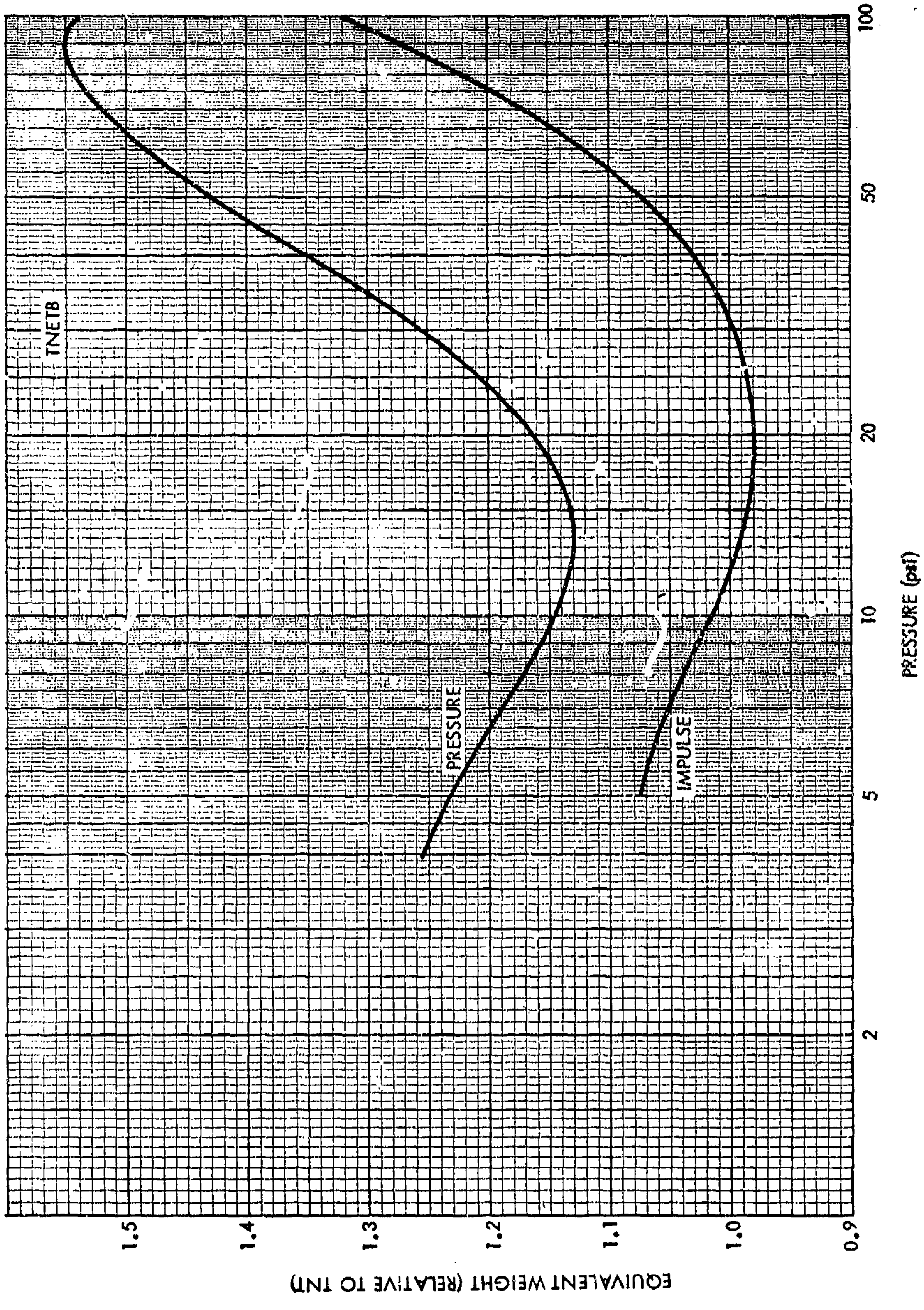

FIG. 2g FREE - AIR EQUIVALENT WEIGHT VS PEAK OVERPRESSURE FOR TNETB

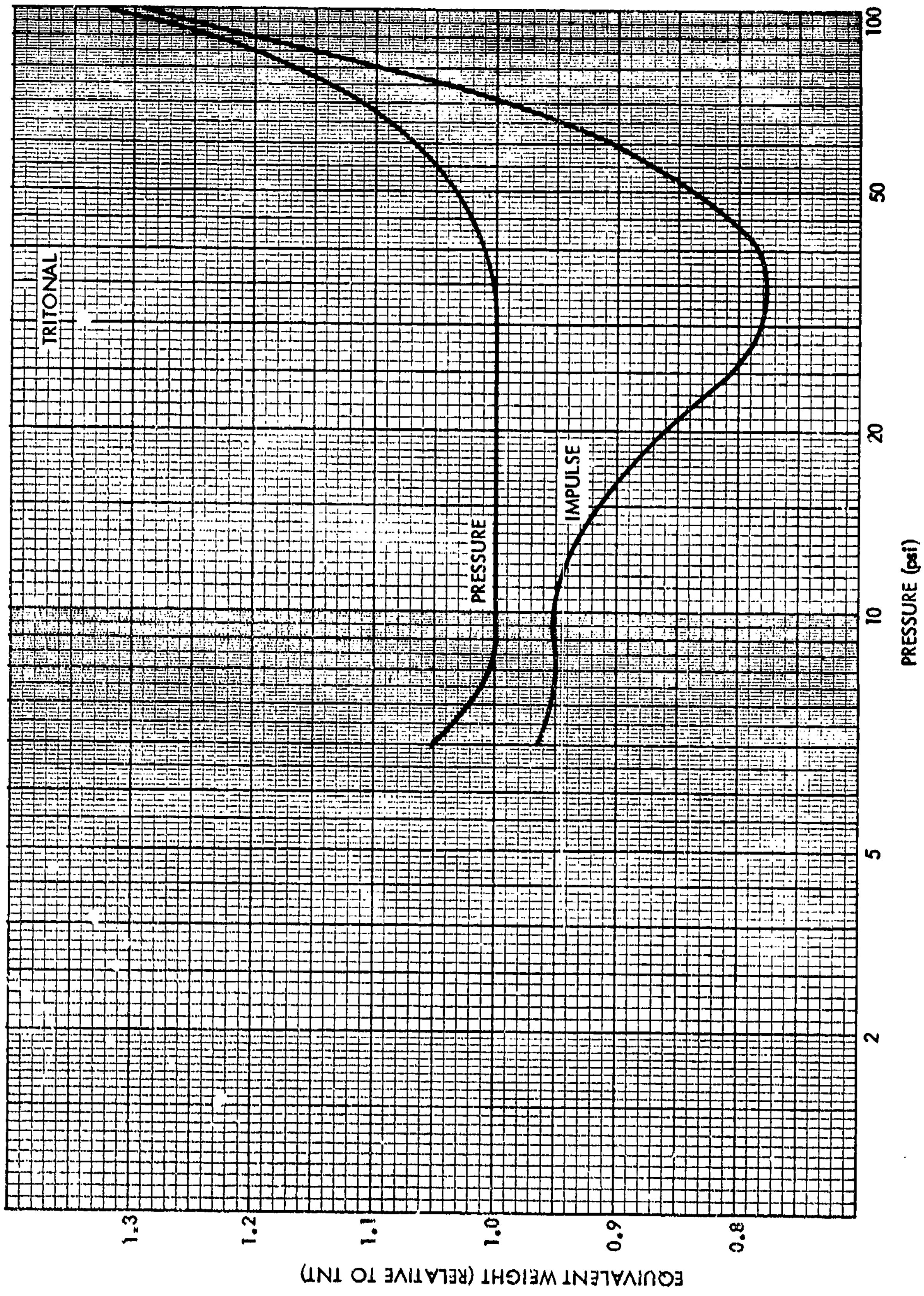

FIG. 2h FREE - AIR EQUIVALENT WEIGHT VS PEAK OVERPRESSURE FOR TRITONAL

Explosive		Eq. Weight Pressure	Eq. Weight Impulse	Pressure Range
Composition A-3		1.09	1.07	5-50
Composition B	X	1.11	0.98	5-50
Composition C-4	X	1.37	1.19	10-100
Cyclotol(70/30)[1]		1.14	1.09	5-50
HBX-1	X	1.17	1.16	5-20
HBX-3	X	1.14	0.97	5-25
H-6	X	1.38	1.15	5-100
Minol II		1.20	1.11	3-20
Octol {70/30 75/25}[2]		1.06		E*
PETN		1.27		5-100
Pentolite	X	1.42	1.00	5-100
		1.38	1.14	5-600
Picratol		0.90	0.93	
Tetryl		1.07		3-20
Tetrytol {75/25 70/30 65/35}[3]		1.06		E *
TNETB	X	1.36	1.10	5-100
TNT		1.00	1.00	STANDARD
TRITONAL	X	1.07	0.96	5-100

[1] RDX/TNT

[2] HMX/TNT

[3] TETRYL/TNT

*E = estimated

X = indicates that equivalent weight vs pressure is included in Figures 2a-2h.

FIG. 21 AVERAGED FREE AIR EQUIVALENT WEIGHTS

EXPLOSIVE	EQUIV. WEIGHT (Rel to TNT)	PRESSURE RANGE (psi)
ANFO (94/6 Ammonium Nitrate/ Fuel Oil)	0.82	1-100
PBX-9404	1.13	5-30
PBX-9010	1.29	5-30
Nitroglycerin Dynamite (50% Strength)	0.9	estimated
Ammonia Dynamite (50% Strength)	0.9	estimated
Ammonia Dynamite (20% Strength)	0.7	estimated
Gelatin Dynamite (50% Strength)	0.8	estimated
Gelatin Dynamite (20% Strength)	0.7	estimated

CAVEAT: This figure presents the best available information; however, it includes surface burst data and estimates for the dynamites. The equivalent weight of dynamite is a strong function of its "strength", i.e., its equivalent nitroglycerin content.

FIG. 2j Average or Estimated Equivalent Weights For Several Explosives (Pressure Criterion)

CHAPTER 3

SHOCK WAVE PARAMETERS FOR SPHERICAL TNT EXPLOSIONS IN AIR

The information on Figures 3a through 3t represent a composite of available spherical, bare-charge, free-air TNT data. The peak pressure and time of arrival information is good to ± 10% while the positive impulse and positive duration are good to ± 20% for a given distance.

Figures 3a through 3c present data scaled to a one-pound charge. These are, thus, the figures which would be used to obtain scaled information.

The dotted portions of Figure 3a represent hydrodynamic computer calculations, extending the curves into regions where there is little available data; figure 3b presents calculations of the pressure-distance curve to low pressures. Figures 3c through 3t present information, in tabulated form, on shock wave parameters for some commonly used charge weights.

Problem Example 1

What is the peak pressure, time of arrival, positive duration and positive impulse 20 feet from a 100-pound TNT charge detonated in free air?

Solution 1

(a) From Chapter 1, Equation 4, $\lambda = R/W^{1/3} = 20 \text{ ft}/(100 \text{ lb})^{1/3}$
$= 4.309 \text{ ft/lb}^{1/3}$

(b) Go to Figure 3a and read off the values of the scaled parameters at this scaled distance.

$P = 40$ psi	for pressure
$TOA = 2.0 \text{ msec/lb}^{1/3}$	for scaled time-of-arrival
$\tau = 1.6 \text{ msec/lb}^{1/3}$	for scaled duration
$I = 11.8 \text{ psi-msec/lb}^{1/3}$	for scaled positive impulse

(c) From Equations 5 and 6 from Chapter 1, to obtain unscaled data from Hopkinson-scaled data, multiply by $W^{1/3}$, remembering that pressure is not scaled.

$P = 40$ psi

$TOA = 2.0 \text{ msec/lb}^{1/3} \times (100 \text{ lb})^{1/3} = 9.3$ msec

$\tau = 1.6 \text{ msec/lb}^{1/3} \times (100 \text{ lb})^{1/3} = 7.36$ msec

$I = 11.8 \text{ psi-msec/lb}^{1/3} \times (100 \text{ lb})^{1/3} = 54.3$ psi-msec

Solution 2 For more accurate values, for a 100-pound charge, go to the Figure 2ℓ for this charge weight and simply read across at the appropriate distance.

$p = 40$ psi
$TOA = 9.511$ msec
$\tau = 7.38$ msec
$I = 54.77$ psi-msec

For explosives other than TNT, determine their equivalent charge weight by multiplying their charge weight by the appropriate equivalent weight factor given in Chapter 2.

For ambient air at other than 20°C, the time of arrival is corrected by multiplying by these factors.

Temperature (°C)	Correction Factor
-40	1.12
-30	1.10
-20	1.08
-10	1.06
0	1.04
10	1.02
20	1.00
30	0.98
40	0.97

Problem Example 2

At a pressure level of 100 psi, what is the time of arrival, positive duration, and positive impulse produced by the detonation of 55 pounds of tritonal at an ambient temperature of -40°C?

Solution

(a) From Figure 2h, the equivalent weight (based on peak pressure) for tritonal is 1.32, and for positive impulse 1.29 at a pressure of 100 psi. Hence, 55 lb of Tritonal equals 72.6 lbs of TNT at the 100 psi level, and 55 lbs of Tritonal equals 71.0 lbs of TNT for impulse at the 100 psi level. For TOA and τ, use the TNT equivalencies for pressure and impulse respectively

(b) From Figure 3c, determine the scaled parameters of interest for 1 lb of TNT at the 100 psi level. Thus, 100 psi occurs at $\lambda = 2.89$, and at this λ,

$$\begin{aligned} TOA &= .94 \text{ msec/lb}^{1/3} \\ \tau &= .\text{[illegible] msec/lb}^{1/3} \\ I &= 14.2 \text{ psi-msec/lb}^{1/3} \end{aligned}$$

(c) For TOA, for 72.6 lbs of TNT (or 55 lbs of Tritonal)
$TOA = .94 \text{ lb}^{1/3} \times 72.6^{1/3}$ lbs
[$72.6^{1/3} = 4.2$ from Fig. 1e],

Hence, TOA = .94 X 4.2 = 3.95 msec, but this is for conditions at 20°C

(d) For −40°C, the TOA is increased by 1.12 (see chart above)
Hence, TOA = 3.95 X 1.12 = 4.42 msec

(e) For duration and impulse, 55 lbs of Tritonal = 71.0 lb of TNT. ($71.0^{1/3} = 4.1$ from Fig. 1e)
Hence, $\tau = .84 \times 4.1 = 3.4$ msec
and $I = 14.2 \times 4.1 = 58.2$ psi-msec

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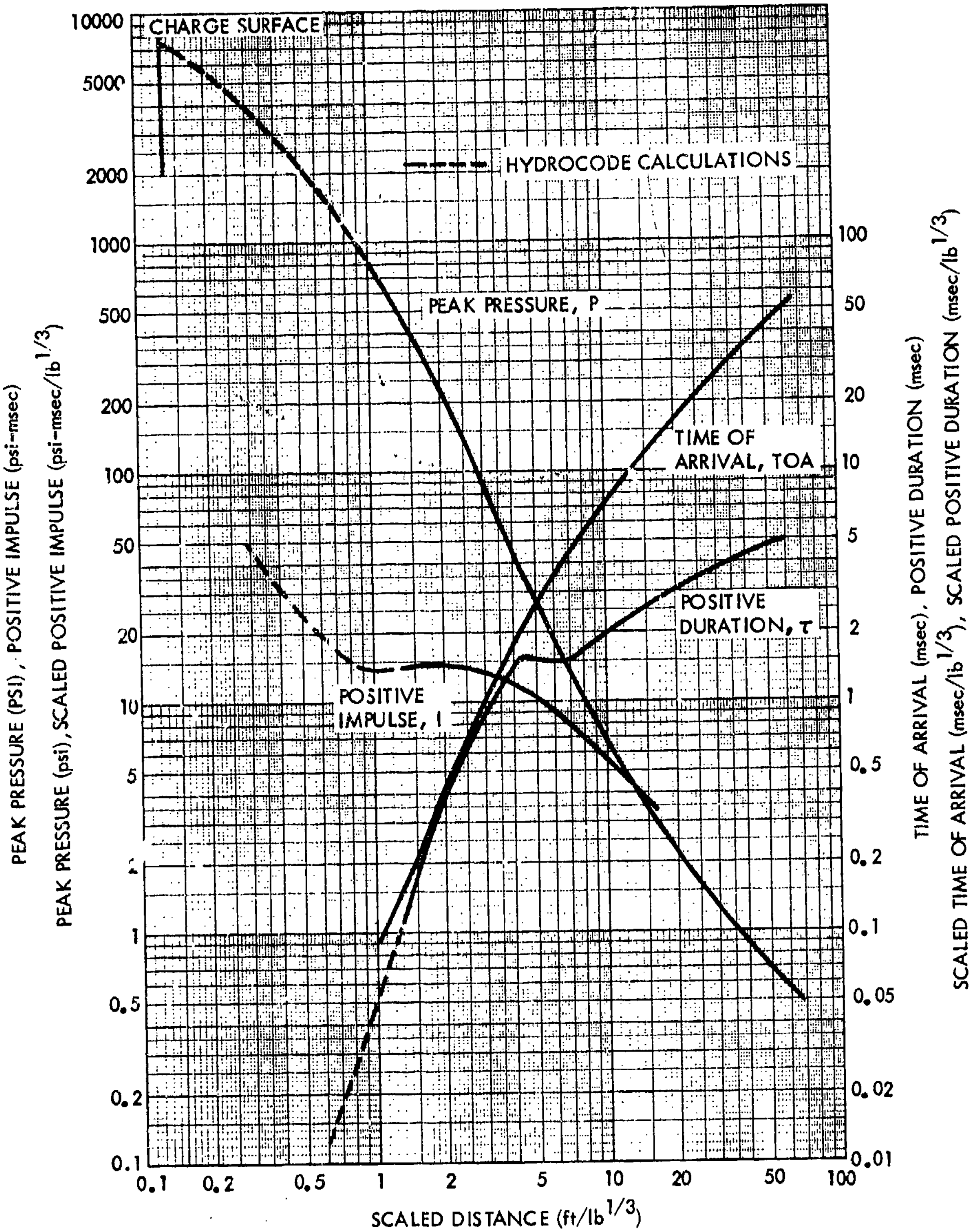


FIG. 3a SHOCK WAVE PARAMETERS FOR A ONE POUND SPHERICAL TNT EXPLOSION IN FREE AIR

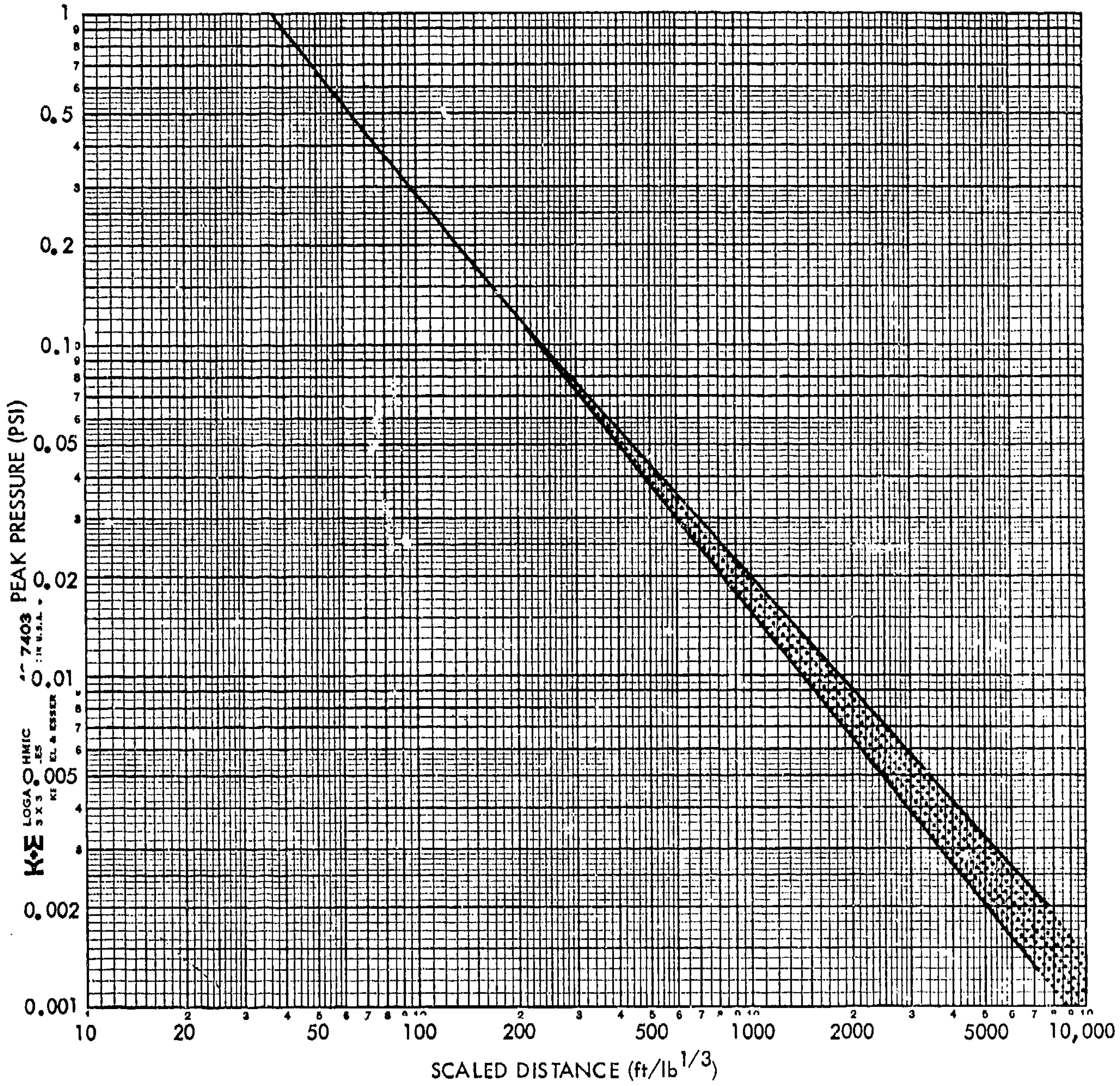


FIG. 3b LOW PRESSURE REGIME FOR A ONE-POUND SPHERICAL TNT EXPLOSION IN FREE-AIR (BASED ON COMPUTER CALCULATIONS)

t = 20°C
C = 1126 ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	1.018	.092		
600	1.195	.139		
500	1.316	.174	.114	14.52
400	1.476	.228	.166	14.71
300	1.707	.313	.263	14.89
250	1.868	.381	.340	14.94
200	2.084	.479	.438	14.93
150	2.393	.627	.580	14.75
100	2.888	.939	.845	14.18
80	3.189	1.146	1.01	13.72
60	3.606	1.464	1.28	13.02
50	3.885	1.700	1.40	12.54
40	4.308	2.049	1.59	11.80
30	4.937	2.596	1.58	10.74
25	5.343	2.978	1.55	10.10
20	5.884	3.500	1.50	9.32
15	6.698	4.293	1.52	8.28
10	8.144	5.698	1.73	6.82
8	9.141	6.652	1.88	6.05
6	10.71	8.136	2.12	5.12
5	11.92	9.264	2.27	4.59
4	13.68	10.89	2.48	4.01
3	16.53	13.49	2.80	3.42
2.5	18.76	15.51	3.00	
2.0	22.04	18.47	3.30	
1.5	27.39	23.27	3.78	
1.0	37.69	32.48	4.30	
0.8	45.12	39.11	4.60	
0.6	56.98	49.69	5.00	
0.5	66.04	57.76		

CAVEAT: The number of significant figures shown in all tables are derived from computer printouts; they do not signify the accuracy of the data.

FIG. 3c ONE POUND TNT

t = 20°C
C = 1126 ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	1.283	.116		
600	1.506	.175		
500	1.658	.219	.144	18.29
400	1.860	.287	.209	18.53
300	2.151	.394	.331	18.76
250	2.354	.480	.428	18.82
200	2.626	.604	.552	18.81
150	3.015	.790	.731	18.58
100	3.639	1.183	1.06	17.87
80	4.018	1.444	1.27	17.29
60	4.543	1.845	1.61	16.40
50	4.895	2.142	1.76	15.80
40	5.428	2.582	2.00	14.87
30	6.220	3.271	1.99	13.53
25	6.732	3.752	1.95	12.73
20	7.413	4.410	1.89	11.74
15	8.439	5.409	1.92	10.43
10	10.26	7.179	2.18	8.59
8	11.52	8.381	2.37	7.62
6	13.49	10.25	2.67	6.45
5	15.02	11.67	2.86	5.78
4	17.24	13.72	3.12	5.05
3	20.83	17.00	3.53	4.31
2.5	23.64	19.54	3.78	
2.0	27.77	23.27	4.16	
1.5	34.51	29.32	4.76	
1.0	47.49	40.92	5.42	
0.8	56.05	49.28	5.80	
0.6	71.79	62.61	6.30	
0.5	83.21	72.77		

FIG. 3d TWO POUNDS TNT

$t = 20^{\circ}C$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	1.741	.157		
600	2.043	.238		
500	2.250	.298	.195	24.83
400	2.524	.390	.284	25.15
300	2.919	.535	.450	25.46
250	3.194	.652	.581	25.55
200	3.564	.819	.749	25.53
150	4.092	1.072	.992	25.22
100	4.938	1.606	1.44	24.25
80	5.453	1.960	1.73	23.46
60	6.166	2.503	2.19	22.26
50	6.643	2.907	2.39	21.44
40	7.367	3.504	2.72	20.18
30	8.442	4.439	2.70	18.37
25	9.136	5.092	2.65	17.27
20	10.06	5.985	2.56	15.94
15	11.45	7.341	2.60	14.16
10	13.93	9.743	2.96	11.66
8	15.63	11.37	3.21	10.35
6	18.31	13.91	3.63	8.76
5	20.38	15.84	3.88	7.85
4	23.39	18.62	4.24	6.86
3	28.27	23.07	4.79	5.85
2.5	32.08	26.52	5.13	
2.0	37.69	31.58	5.64	
1.5	46.84	39.79	6.46	
1.0	64.45	55.54	7.35	
0.8	77.15	66.88	7.87	
0.6	97.43	84.97	8.55	
0.5	112.9	98.77		

FIG. 3e FIVE POUNDS TNT

$t = 20^{\circ}C$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	2.036	.184		
600	2.390	.278		
500	2.632	.348	.228	29.04
400	2.952	.456	.332	29.42
300	3.414	.626	.526	29.78
250	3.736	.762	.680	29.88
200	4.168	.958	.876	29.86
150	4.786	1.254	1.16	29.50
100	5.776	1.878	1.69	28.36
80	6.378	2.292	2.02	27.44
60	7.212	2.928	2.56	26.04
50	7.770	3.400	2.80	25.08
40	8.616	4.098	3.18	23.60
30	9.874	5.192	3.16	21.48
25	10.69	5.956	3.10	20.20
20	11.77	7.00	3.00	18.64
15	13.40	8.59	3.02	16.56
10	16.29	11.40	3.46	13.64
8	18.28	13.30	3.76	12.10
6	21.42	16.27	4.24	10.24
5	23.84	18.53	4.54	9.18
4	27.36	21.78	4.96	8.02
3	33.06	26.98	5.60	6.84
2.5	37.52	31.02	6.00	
2.0	44.08	36.94	6.60	
1.5	54.78	46.54	7.56	
1.0	75.38	64.96	8.60	
0.8	90.24	78.22	9.20	
0.6	114.0	99.38	10.00	
0.5	132.1	115.5		

FIG. 3f EIGHT POUNDS TNT

$t = 20^{\circ}C$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	2.193	.198		
600	2.575	.299		
500	2.835	.375	.246	31.28
400	3.180	.491	.358	31.69
300	3.678	.674	.567	32.08
250	4.024	.821	.733	32.19
200	4.490	1.032	.944	32.17
150	5.156	1.351	1.25	31.78
100	6.222	2.023	1.82	30.55
80	6.870	2.469	2.18	29.56
60	7.769	3.154	2.76	28.05
50	8.370	3.663	3.02	27.02
40	9.281	4.414	3.43	25.42
30	10.64	5.593	3.40	23.14
25	11.51	6.416	3.34	21.76
20	12.68	7.541	3.23	20.08
15	14.43	9.249	3.27	17.84
10	17.55	12.28	3.73	14.69
8	19.69	14.33	4.05	13.03
6	23.07	17.53	4.57	11.03
5	25.68	19.96	4.89	9.89
4	29.47	23.46	5.34	8.64
3	35.61	29.06	6.03	7.37
2.5	40.42	33.42	6.46	
2.0	47.48	39.79	7.11	
1.5	59.01	50.13	8.14	
1.0	81.20	69.98	9.26	
0.8	97.21	84.26	9.91	
0.6	122.8	107.1	10.77	
0.5	142.3	122.4		

FIG. 3g TEN POUNDS TNT

$t = 20^{\circ}\mathrm{C}$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	2.763	.250		
600	3.244	.377		
500	3.572	.472	.309	39.41
400	4.006	.619	.451	39.93
300	4.634	.850	.714	40.42
250	5.071	1.034	.923	40.55
200	5.657	1.300	1.19	40.53
150	6.496	1.702	1.57	40.04
100	7.839	2.549	2.29	38.49
80	8.656	3.111	2.74	37.24
60	9.788	3.974	3.47	35.34
50	10.55	4.615	3.80	34.04
40	11.69	5.562	4.32	32.03
30	13.40	7.047	4.29	29.15
25	14.50	8.084	4.21	27.42
20	15.97	9.500	4.07	25.30
15	18.18	11.65	4.13	22.48
10	22.11	15.47	4.70	18.51
8	24.81	18.06	5.10	16.42
6	29.07	22.08	5.75	13.90
5	32.36	25.15	6.16	12.46
4	37.13	29.56	6.73	10.88
3	44.87	36.62	7.60	9.28
2.5	50.92	42.10	8.14	
2.0	59.83	50.14	8.96	
1.5	74.35	63.16	10.26	
1.0	102.3	88.16	11.67	
0.8	122.4	106.2	12.49	
0.6	154.7	134.9	13.57	
0.5	179.3	156.8		

FIG. 3h TWENTY POUNDS TNT

$t = 20^{\circ}C$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	3.054	.276		
600	3.585	.417		
500	3.948	.522	.342	43.56
400	4.428	.684	.498	44.13
300	5.121	.939	.789	44.67
250	5.604	1.143	1.02	44.82
200	6.252	1.437	1.31	44.79
150	7.179	1.881	1.74	44.25
100	8.664	2.817	2.53	42.54
80	9.567	3.438	3.03	41.16
60	10.82	4.392	3.84	39.06
50	11.66	5.100	4.20	37.62
40	12.92	6.147	4.77	35.40
30	14.81	7.788	4.74	32.22
25	16.03	8.934	4.65	30.30
20	17.65	10.50	4.50	27.96
15	20.09	12.88	4.56	24.84
10	24.43	17.09	5.19	20.46
8	27.42	19.96	5.64	18.15
6	32.13	24.41	6.36	15.36
5	35.76	27.79	6.81	13.77
4	41.04	32.67	7.44	12.03
3	49.59	40.47	8.40	10.26
2.5	56.28	46.53	9.00	
2.0	66.12	55.41	9.90	
1.5	82.17	69.81	11.34	
1.0	113.1	97.44	12.30	
0.8	135.4	117.3	13.80	
0.6	170.9	149.1	15.00	
0.5	198.1	173.3		

FIG. 3i TWENTY-SEVEN POUNDS TNT

$t = 20^{\circ}C$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	3.750	.339		
600	4.402	.512		
500	4.848	.641	.420	53.49
400	5.438	.840	.612	54.19
300	6.289	1.153	.969	54.86
250	6.882	1.404	1.25	55.04
200	7.678	1.765	1.61	55.00
150	8.816	2.310	2.14	54.34
100	10.64	3.459	3.11	52.24
80	11.75	4.222	3.72	50.54
60	13.28	5.393	4.72	47.97
50	14.31	6.263	5.16	46.20
40	15.87	7.549	5.86	43.47
30	18.19	9.564	5.82	39.57
25	19.68	10.97	5.71	37.21
20	21.68	12.89	5.53	34.34
15	24.68	15.82	5.60	30.50
10	30.00	20.99	6.37	25.13
8	33.68	24.51	6.93	22.29
6	39.46	29.97	7.81	18.86
5	43.91	34.13	8.36	16.91
4	50.40	40.12	9.14	14.77
3	60.90	49.70	10.32	12.60
2.5	69.11	57.14	11.05	
2.0	81.20	68.04	12.16	
1.5	100.9	85.73	13.93	
1.0	138.9	119.7	15.84	
0.8	166.2	144.1	16.95	
0.6	209.9	183.1	18.42	
0.5	243.3	212.8		

FIG. 3j FIFTY POUNDS TNT

$t = 20^\circ C$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	4.072	.368		
600	4.780	.556		
500	5.264	.696	.456	58.08
400	5.904	.912	.664	58.84
300	6.828	1.252	1.05	59.56
250	7.472	1.524	1.36	59.76
200	8.336	1.916	1.75	59.72
150	9.572	2.508	2.32	59.00
100	11.55	3.756	3.38	56.72
80	12.76	4.584	4.04	54.88
60	14.42	5.856	5.12	52.08
50	15.54	6.800	5.60	50.16
40	17.23	8.196	6.36	47.20
30	19.75	10.38	6.32	42.96
25	21.37	11.91	6.20	40.40
20	23.54	14.00	6.00	37.28
15	26.79	17.17	6.08	33.12
10	32.58	22.79	6.92	27.28
8	36.56	26.61	7.52	24.20
6	42.84	32.54	8.48	20.48
5	47.68	37.06	9.08	18.36
4	54.72	43.56	9.92	16.04
3	66.12	53.96	11.20	13.68
2.5	75.04	62.04	12.00	
2.0	88.16	73.88	13.20	
1.5	109.6	93.08	15.12	
1.0	150.8	129.9	17.20	
0.8	180.5	156.4	18.40	
0.6	227.9	198.8	20.00	
0.5	264.2	231.0		

FIG. 3k SIXTY-FOUR POUNDS TNT

t = 20°C
C = 1126 ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	4.725	.427		
600	5.547	.645		
500	6.108	.808	.529	67.40
400	6.851	1.058	.771	68.28
300	7.923	1.453	1.22	69.11
250	8.670	1.768	1.58	69.35
200	9.673	2.223	2.03	69.30
150	11.11	2.910	2.69	68.46
100	13.40	4.358	3.92	65.82
80	14.80	5.319	4.69	63.68
60	16.74	6.795	5.94	60.43
50	18.03	7.891	6.50	58.21
40	20.00	9.511	7.38	54.77
30	22.92	12.05	7.33	49.85
25	24.80	13.82	7.19	46.88
20	27.31	16.25	6.96	43.26
15	31.09	19.93	7.06	38.43
10	37.80	26.45	8.03	31.66
8	42.43	30.88	8.73	28.08
6	49.71	37.76	9.84	23.76
5	55.33	43.00	10.54	21.30
4	63.50	50.55	11.51	18.61
3	76.73	62.62	13.00	15.87
2.5	87.03	71.99	13.92	
2.0	102.3	85.73	15.32	
1.5	127.1	108.0	17.55	
1.0	174.9	150.8	19.96	
0.8	209.4	181.5	21.35	
0.6	264.5	230.6	23.21	
0.5	306.5	268.1		

FIG. 31 ONE HUNDRED POUNDS TNT

$t = 20^{\circ}\mathrm{C}$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	5.090	.460		
600	5.975	.695		
500	6.580	.870	.570	72.60
400	7.380	1.140	.830	73.55
300	8.535	1.565	1.32	74.45
250	9.340	1.905	1.70	74.70
200	10.42	2.395	2.19	74.65
150	11.96	3.135	2.90	73.75
100	14.44	4.695	4.22	70.90
80	15.94	5.730	5.05	68.60
60	18.03	7.320	6.40	65.10
50	19.42	8.500	7.00	62.70
40	21.54	10.24	7.95	59.00
30	24.68	12.98	7.90	53.70
25	26.72	14.89	7.75	50.50
20	29.42	17.50	7.50	46.60
15	33.49	21.46	7.60	41.40
10	40.72	28.49	8.65	34.10
8	45.70	33.26	9.40	30.25
6	53.55	40.68	10.60	25.60
5	59.60	46.32	11.35	22.95
4	68.40	54.45	12.40	20.05
3	82.65	67.45	14.00	17.10
2.5	93.80	77.55	15.00	
2.0	110.2	92.35	16.50	
1.5	137.0	116.4	18.90	
1.0	188.4	162.4	21.50	
0.8	225.6	195.6	23.00	
0.6	284.9	248.4	25.00	
0.5	330.2	288.8		

FIG. 3m ONE HUNDRED TWENTY FIVE POUNDS TNT

$t = 20^{o}C$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	5.953	.538		
600	6.988	.813		
500	7.696	1.018	.667	84.91
400	8.632	1.333	.971	86.02
300	9.983	1.830	1.54	87.08
250	10.92	2.228	1.99	87.37
200	12.19	2.801	2.56	87.31
150	13.99	3.667	3.39	86.26
100	16.89	5.491	4.94	82.93
80	18.65	6.702	5.91	80.24
60	21.09	8.562	7.49	76.14
50	22.72	9.942	8.19	73.33
40	25.19	11.98	9.30	69.01
30	28.87	15.18	9.24	62.81
25	31.25	17.42	9.06	59.07
20	34.41	20.47	8.77	54.50
15	39.17	25.11	8.89	48.42
10	47.63	33.32	10.12	39.88
8	53.46	38.90	10.99	35.38
6	62.63	47.58	12.40	29.94
5	69.71	54.18	13.28	26.84
4	80.00	63.69	14.50	23.45
3	96.67	78.89	16.37	20.00
2.5	109.7	90.70	17.54	
2.0	128.9	108.0	19.30	
1.5	160.2	136.1	22.11	
1.0	220.4	189.9	25.15	
0.8	263.9	228.7	26.90	
0.6	333.2	290.6	29.24	
0.5	386.2	337.8		

FIG. 3n TWO HUNDRED POUNDS TNT

t = 20°C
C = 1126 ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	6.108	.552		
600	7.170	.834		
500	7.896	1.044	.684	87.12
400	8.856	1.368	.996	88.26
300	10.24	1.878	1.58	89.34
250	11.21	2.286	2.04	89.64
200	12.50	2.874	2.63	89.58
150	14.36	3.762	3.48	88.50
100	17.33	5.634	5.07	85.08
80	19.13	6.876	6.06	82.32
60	21.64	8.784	7.68	78.12
50	23.31	10.20	8.40	75.24
40	25.85	12.29	9.54	70.80
30	29.62	15.58	9.48	64.44
25	32.06	17.87	9.30	60.60
20	35.30	21.00	9.00	55.92
15	40.19	25.76	9.12	49.68
10	48.86	34.19	10.38	40.92
8	54.85	39.91	11.28	36.30
6	64.26	48.82	12.72	30.72
5	71.52	55.58	13.62	27.54
4	82.08	65.34	14.88	24.06
3	99.18	80.94	16.80	20.52
2.5	112.6	93.06	18.00	
2.0	132.2	110.8	19.80	
1.5	164.3	139.6	22.68	
1.0	226.1	194.9	25.80	
0.8	270.7	234.7	27.60	
0.6	341.9	298.1	30.00	
0.5	396.2	346.6		

FIG. 3o TWO HUNDRED SIXTEEN POUNDS TNT

t = 20°C
C = 1126 ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	7.126	.644		
600	8.365	.973		
500	9.212	1.218	.798	101.6
400	10.33	1.596	1.16	103.0
300	11.95	2.191	1.84	104.2
250	13.08	2.667	2.38	104.6
200	14.59	3.353	3.07	104.5
150	16.75	4.389	4.06	103.2
100	20.22	6.573	5.92	99.26
80	22.32	8.022	7.07	96.04
60	25.24	10.25	8.96	91.14
50	27.20	11.90	9.80	87.78
40	30.16	14.34	11.13	82.60
30	34.56	18.17	11.06	75.18
25	37.40	20.85	10.85	70.70
20	41.19	24.50	10.50	65.24
15	46.89	30.05	10.64	57.96
10	57.01	39.89	12.11	47.74
8	63.99	46.56	13.16	42.35
6	74.97	56.95	14.84	35.84
5	83.44	64.85	15.89	32.13
4	95.76	76.23	17.36	28.07
3	115.7	94.43	19.60	23.94
2.5	131.3	108.6	21.00	
2.0	154.3	129.3	23.10	
1.5	191.7	162.9	26.46	
1.0	263.8	227.4	30.10	
0.8	315.8	273.8	32.20	
0.6	398.9	347.8	35.00	
0.5	462.3	404.3		

FIG. 3p THREE HUNDRED FORTY THREE POUNDS TNT

$t = 20^{\circ}C$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	8.080	.730		
600	9.485	1.103		
500	10.45	1.381	.905	115.2
400	11.72	1.810	1.32	116.8
300	13.55	2.484	2.09	118.2
250	14.83	3.024	2.07	118.6
200	16.54	3.802	3.48	118.5
150	18.99	4.977	4.60	117.1
100	22.92	7.453	6.71	112.6
80	25.31	9.096	8.02	108.9
60	28.62	11.62	10.16	103.3
50	30.84	13.49	11.11	99.53
40	34.19	16.26	12.62	93.66
30	39.18	20.60	12.54	85.24
25	42.41	23.64	12.30	80.16
20	46.70	27.78	11.91	73.97
15	53.16	34.07	12.06	65.72
10	64.64	45.23	13.73	54.13
8	72.55	52.90	14.92	48.02
6	85.01	64.58	16.83	40.64
5	94.61	73.53	18.02	36.43
4	108.6	86.43	19.68	31.83
3	131.2	107.1	22.22	27.14
2.5	148.9	123.1	23.81	
2.0	174.9	146.6	26.19	
1.5	217.4	184.7	30.00	
1.0	299.1	257.8	34.13	
0.8	358.1	310.4	36.51	
0.6	452.3	367.4	39.69	
0.5	524.2	458.4		

FIG. 3q FIVE HUNDRED POUNDS TNT

$t = 20^{\circ}\mathrm{C}$
$C \approx 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	8.144	.736		
600	9.560	1.112		
500	10.53	1.392	.912	116.2
400	11.81	1.824	1.32	117.7
300	13.66	2.504	2.10	119.1
250	14.94	3.048	2.72	119.5
200	16.67	3.832	3.50	119.4
150	19.14	5.016	4.64	118.0
100	23.10	7.512	6.76	133.4
80	25.51	9.168	8.08	109.7
60	28.85	11.71	10.24	104.2
50	31.08	13.60	11.20	100.3
40	34.46	16.39	12.72	94.40
30	39.50	20.77	12.64	85.92
25	42.74	23.82	12.40	80.80
20	47.07	28.00	12.00	74.56
15	53.58	34.34	12.16	66.24
10	65.15	45.58	13.84	54.56
8	73.13	53.22	15.04	48.40
6	85.68	65.09	16.96	40.96
5	95.36	74.11	18.16	36.72
4	109.4	87.12	19.84	32.08
3	132.2	107.9	22.40	27.36
2.5	150.1	124.1	24.00	
2.0	176.3	147.8	26.40	
1.5	219.1	186.2	30.24	
1.0	301.5	259.8	34.40	
0.8	361.0	312.9	36.80	
0.6	455.8	397.5	40.00	
0.5	528.3	462.1		

FIG. 3r FIVE HUNDRED TWELVE POUNDS TNT

t = 20°C
C = 1126 ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	9.162	.828		
600	10.76	1.251		
500	11.84	1.566	1.03	130.7
400	13.28	2.052	1.49	132.4
300	15.36	2.817	2.37	134.0
250	16.81	3.429	3.06	134.5
200	18.76	4.311	3.94	134.4
150	21.54	5.643	5.22	132.8
100	25.99	8.451	7.61	127.6
80	28.70	10.31	9.09	123.5
60	32.45	13.18	11.52	117.2
50	34.97	15.30	12.60	112.9
40	38.77	18.44	14.31	106.2
30	44.43	23.36	14.22	96.66
25	48.09	26.80	13.95	90.90
20	52.96	31.50	13.50	83.88
15	60.28	38.64	13.68	74.52
10	73.30	51.28	15.57	61.38
8	82.27	59.87	16.92	54.45
6	96.39	73.22	19.08	46.08
5	107.3	83.88	20.43	41.31
4	123.1	98.01	22.32	36.09
3	148.8	121.4	25.20	30.78
2.5	168.8	139.6	27.00	
2.0	198.4	166.2	29.70	
1.5	246.5	209.4	34.02	
1.0	339.2	292.3	38.70	
0.8	406.1	352.0	41.40	
0.6	512.8	447.2	45.00	
0.5	594.4	519.8		

FIG. 3s SEVEN HUNDRED TWENTY NINE POUNDS TNT

$t = 20^{\circ}C$
$C = 1126$ ft/sec

P (psi)	R (feet)	TOA (msec)	τ (msec)	I (psi-msec)
800	10.18	.915		
600	11.95	1.391		
500	13.16	1.740	1.14	145.2
400	14.76	2.275	1.66	147.1
300	17.07	3.128	2.63	148.9
250	18.68	3.807	3.40	149.4
200	20.84	4.794	4.38	149.3
150	23.93	6.270	5.80	147.5
100	28.88	9.392	8.45	141.8
80	31.89	11.46	10.1	137.2
60	36.06	14.64	12.80	130.2
50	38.85	17.00	14.00	125.4
40	43.08	20.49	15.9	118.0
30	49.37	25.96	15.8	107.4
25	53.43	29.78	15.5	101.0
20	58.84	35.00	15.0	93.2
15	66.98	42.93	15.2	82.8
10	81.44	56.98	17.3	68.2
8	91.41	66.52	18.8	60.5
6	107.1	81.36	21.2	51.2
5	119.2	92.64	22.7	45.9
4	136.8	108.9	24.8	40.1
3	165.3	134.9	28.0	34.2
2.5	187.6	155.1	30.0	
2.0	220.4	184.7	33.0	
1.5	273.9	232.7	37.8	
1.0	376.9	324.8	43.0	
0.8	451.2	391.1	46.0	
0.6	569.8	496.9	50.0	
0.5	660.4	577.6		

FIG. 3t ONE THOUSAND POUNDS TNT

CHAPTER 4

TRIPLE POINT LOCI FOR A TNT CHARGE AT SEA LEVEL

This chapter, in Figures 4b and 4c, describes the locus of the triple point as a function of scaled charge height and scaled horizontal distance.

The triple point represents the location at which the incident wave, reflected wave, and Mach fronts meet. As the reflected wave continues to overtake the incident wave, the triple point rises and the height of the Mach Stem increases (see Figure 4a). At points above the triple point path, two pressure increases will be experienced at a measuring point. The first is due to the incident blast wave, and the second, arriving a short time later, to the reflected wave.

Problem Example 1

What is the height of the triple point at a distance of 24 feet from a 216-pound TNT charge detonated 6 feet above the ground?

Solution

(a) $\lambda_H = 6/(216)^{1/3} = 1 \text{ ft/lb}^{1/3}$

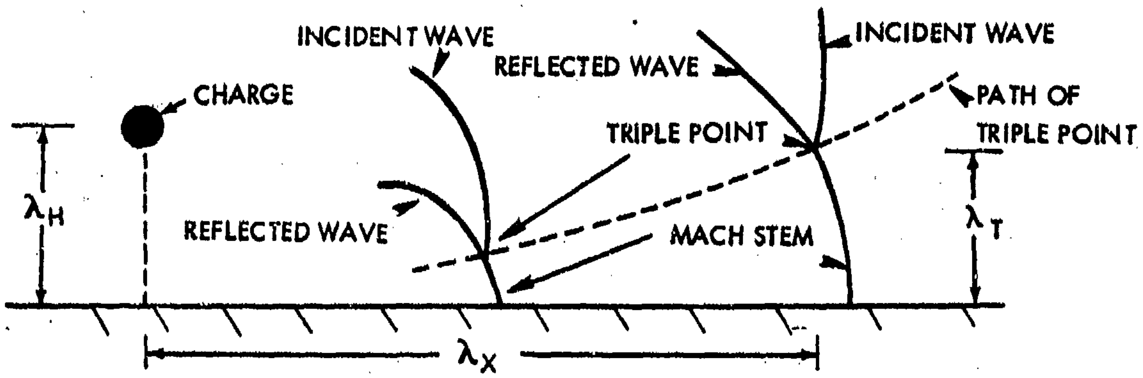
(b) $\lambda_X = 24/(216)^{1/3} = 4 \text{ ft/lb}^{1/3}$

(c) Entering either Figure 4b or 4c with these values, read a $\lambda_T = 1.75 \text{ ft/lb}^{1/3}$

(d) Height of triple point = $\lambda_T \times W^{1/3} = 1.75 \times (216)^{1/3} =$ 10.50 ft

Reference:

(1) Groves, T. K., "A Photo-Optical System of Recording Shock Profiles from Chemical Explosions (U)," Suffield Technical Paper No. 192, 14 Apr 1960



λ_X ≡ SCALED HORIZONTAL DISTANCE TO TRIPLE POINT (FT/(LBS TNT)$^{1/3}$)

λ_H ≡ SCALED CHARGE HEIGHT (FT/(LBS TNT)$^{1/3}$)

λ_T ≡ SCALED HEIGHT OF TRIPLE POINT (FT/(LBS TNT)$^{1/3}$)

FIG. 4a TRIPLE POINT LOCI FOR A TNT CHARGE AT SEA LEVEL

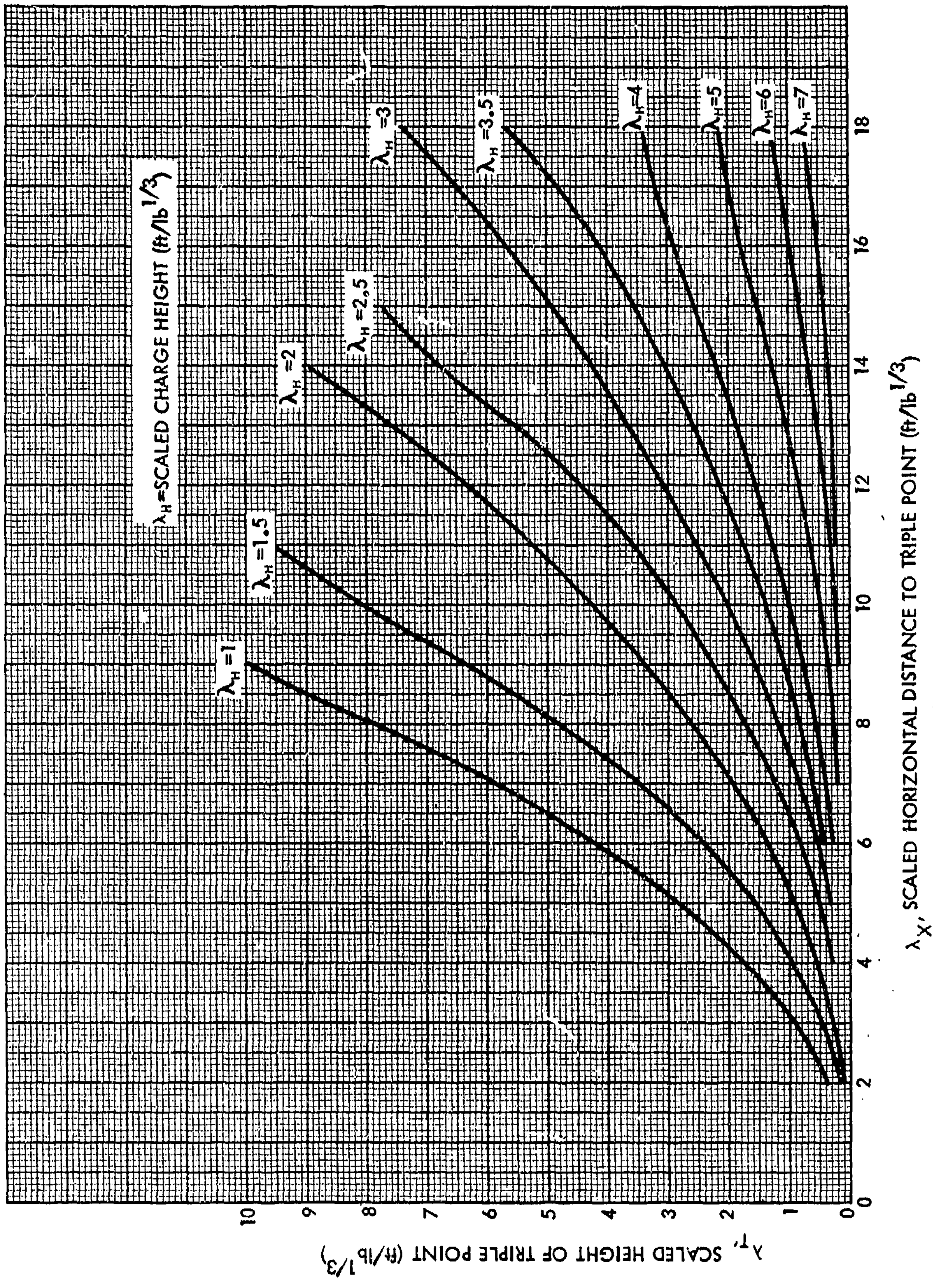


FIG. 4b TRIPLE POINT LOCI FOR A TNT CHARGE AT SEA LEVEL

λ_H	Scaled Charge Height (λ_H)									
	1.0	1.5	2.0	2.5	3.0	3.5	4	5	6	7
2	0.40	.14	.09							
3	0.90	.49	.32							
4	1.75	.97	.58	.26	.14					
5	2.83	1.55	.88	.49	.30					
6	4.25	2.40	1.35	.82	.56	.36	.22			
7	5.85	3.50	1.90	1.18	.83	.58	.38	.18		
8	7.9	4.85	2.60	1.60	1.18	.80	.52	.25		
9	10.0	6.3	3.40	2.20	1.50	1.07	.77	.38	.12	
10		8.1	4.20	2.80	2.0	1.40	.98	.45	.20	
11		9.5	5.20	3.6	2.50	1.77	1.28	.66	.36	.21
12			6.3	4.4	3.0	2.10	1.53	.82	.45	.23
13			7.7	5.5	3.5	2.55	1.85	1.0	.55	.28
14			9.0	6.8	4.4	3.0	2.10	1.20	.66	.35
15				7.7	4.8	3.55	2.50	1.45	.84	.46
16					5.75	4.2	2.75	1.72	1.0	.55
17					6.5	4.85	3.15	1.95	1.15	.66
18					7.4	5.7	3.45	2.15	1.30	.74

λ_H = Scaled charge height (ft/lb$^{1/3}$)

λ_X = Scaled horizontal distance to triple point (ft/lb$^{1/3}$)

FIG. 4c SCALED HEIGHT OF TRIPLE POINT, λ_T

CHAPTER 5

HEIGHT-OF-BURST CURVES--PEAK OVERPRESSURE

The curves in Figures 5a-5c give the peak overpressure along the ground surface as a function of the height-of-burst (HOB) and the horizontal range from ground zero for a scaled, one-pound TNT charge in a sea level atmosphere (14.7 psi). These curves are based on the data from NOLTR 65-218 and private communications from BRL (Ballistics Research Laboratory). The dotted curves are the original curves published in NOLTR 65-218, which were applicable to charge sizes up to 250 pounds. More recent information indicates that the solid curves (based on thousand pound data and larger) are better representations of all the data. This difference is still being investigated. For general application, the solid curves are the ones preferred.

These curves are accurate to no better than ±10% in ground range for a given height of burst.

These curves may be scaled to other yields by the cube root scaling equations, presented in Chapter 1.

$$\lambda_X = R\ (\text{ft})/W\ (\text{lb TNT})^{1/3}$$

$$\lambda_H = H\ (\text{ft})/W\ (\text{lb TNT})^{1/3}$$

where:

λ_X is the scaled horizontal range from ground zero

λ_H is the scaled burst height from ground zero

R is the horizontal range from ground zero

H is the burst height from ground zero

W is the yield of interest

For explosives other than TNT, first determine their TNT equivalence from Chapter 2, then use the above equations.

For pressure other than those given in the figures, a linear interpolation should be used.

Problem Example 1

For a 2 psi pressure level, what is the required ground range from a one-pound TNT charge detonated at a height-of-burst of 25 feet?

Solution

(a) For a $\lambda_H = 25$ ft/(lb TNT)$^{1/3}$, go to Figure 5c

(b) Read from the 2 psi curve, for $\lambda_H = 25$,

$$\lambda_X = 30 \text{ ft/(lb TNT)}^{1/3}$$

(c) As stated above, accuracy is ± 10% in ground range. Thus answer is 30 ft ± 3 ft

Problem Example 2

For an 8.14-lb Pentolite charge fired at altitude of 20 ft, find the horizontal range from ground zero for the 10 psi peak overpressure level.

Solution

(a) From Figure 2f one pound of Pentolite is equivalent to 1.43 lb of TNT at 10 psi. Thus 8.14 lb of Pentolite is equivalent to 11.64 lb of TNT.

(b) $\lambda_H = H/W^{1/3}$

$\lambda_H = 20/(11.64)^{1/3}$

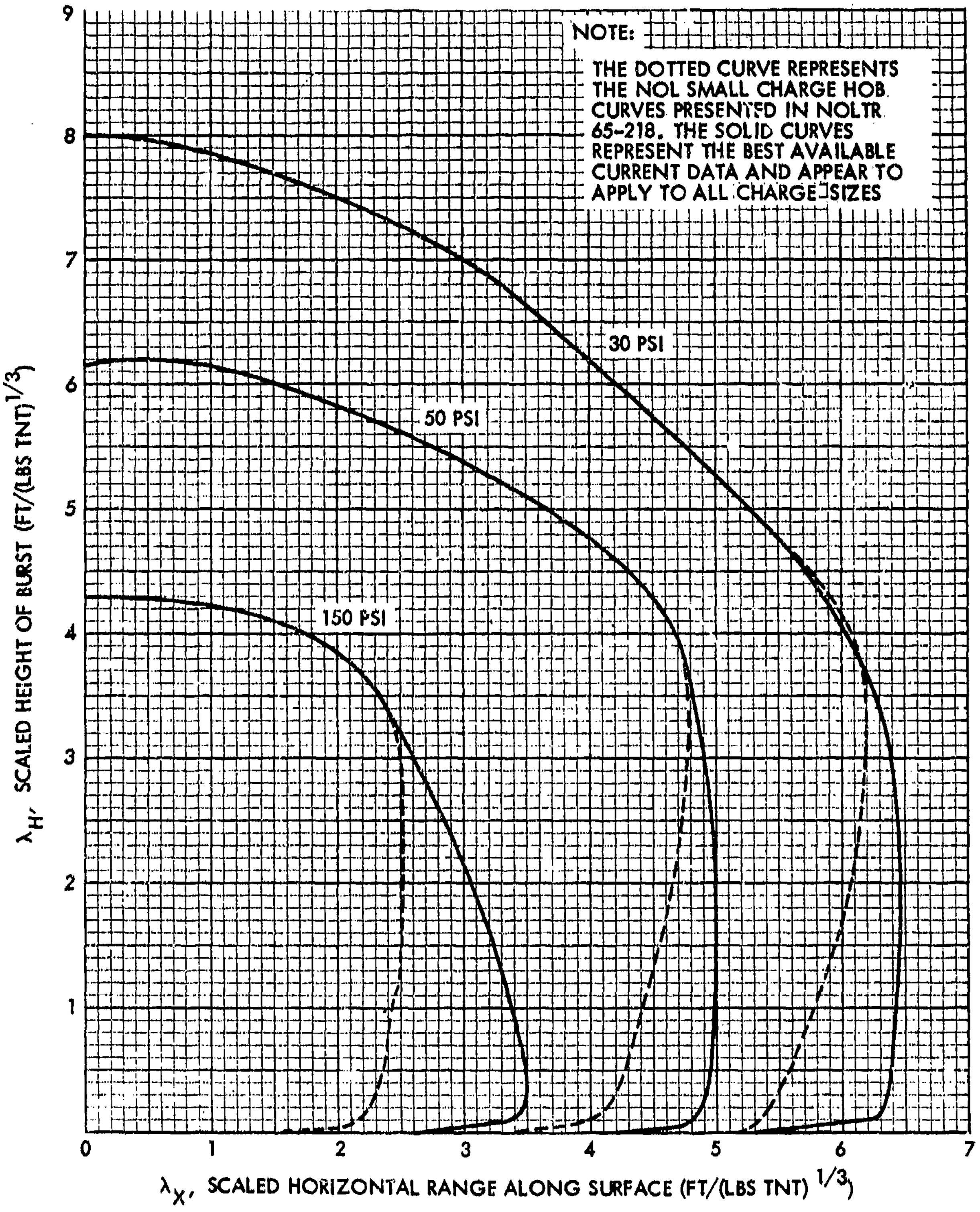
$\lambda_H = 8.8 \text{ ft/(lb TNT)}^{1/3}$

(c) Go to Figure 5b. For a $\lambda_H = 8.8$ ft/(lb TNT)$^{1/3}$, and a pressure of 10 psi, read $\lambda_X = 10.3$ ft/(lb TNT)$^{1/3}$

(d) $\lambda_X = R/W^{1/3}$

$R = \lambda_X \times W^{1/3} = 10.3 \text{ ft/(lb TNT)}^{1/3} \times 2.27 \text{ (lb TNT)}^{1/3}$

$R = 23.4 \text{ ft} \pm 2.3 \text{ ft}$



NOTE:

THE DOTTED CURVE REPRESENTS THE NOL SMALL CHARGE HOB CURVES PRESENTED IN NOLTR 65-218. THE SOLID CURVES REPRESENT THE BEST AVAILABLE CURRENT DATA AND APPEAR TO APPLY TO ALL CHARGE SIZES

FIG. 5a HEIGHT OF BURST CURVES FOR PEAK OVERPRESSURE ON THE GROUND

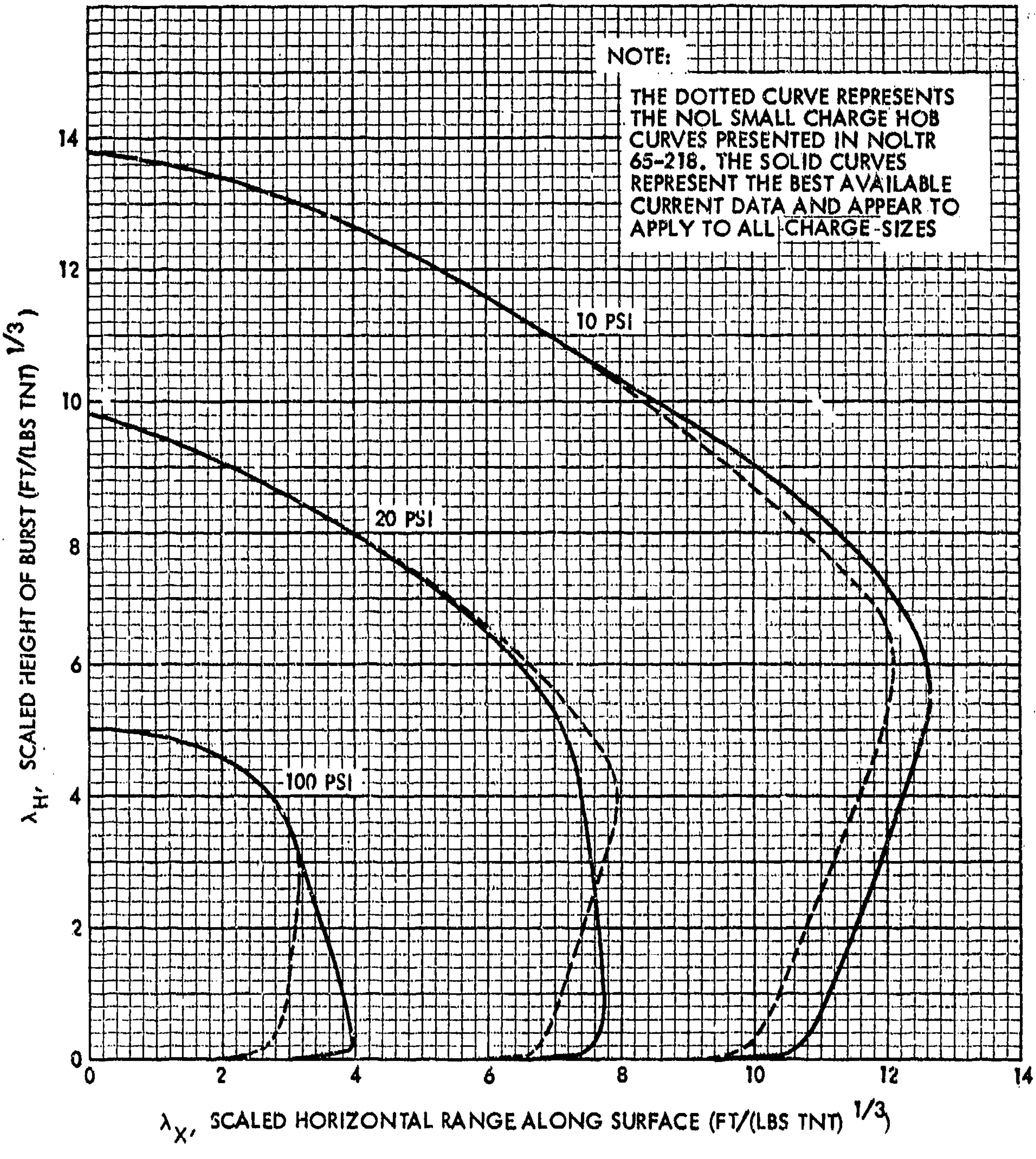


FIG. 5b HEIGHT OF BURST CURVES FOR PEAK OVERPRESSURE ON THE GROUND

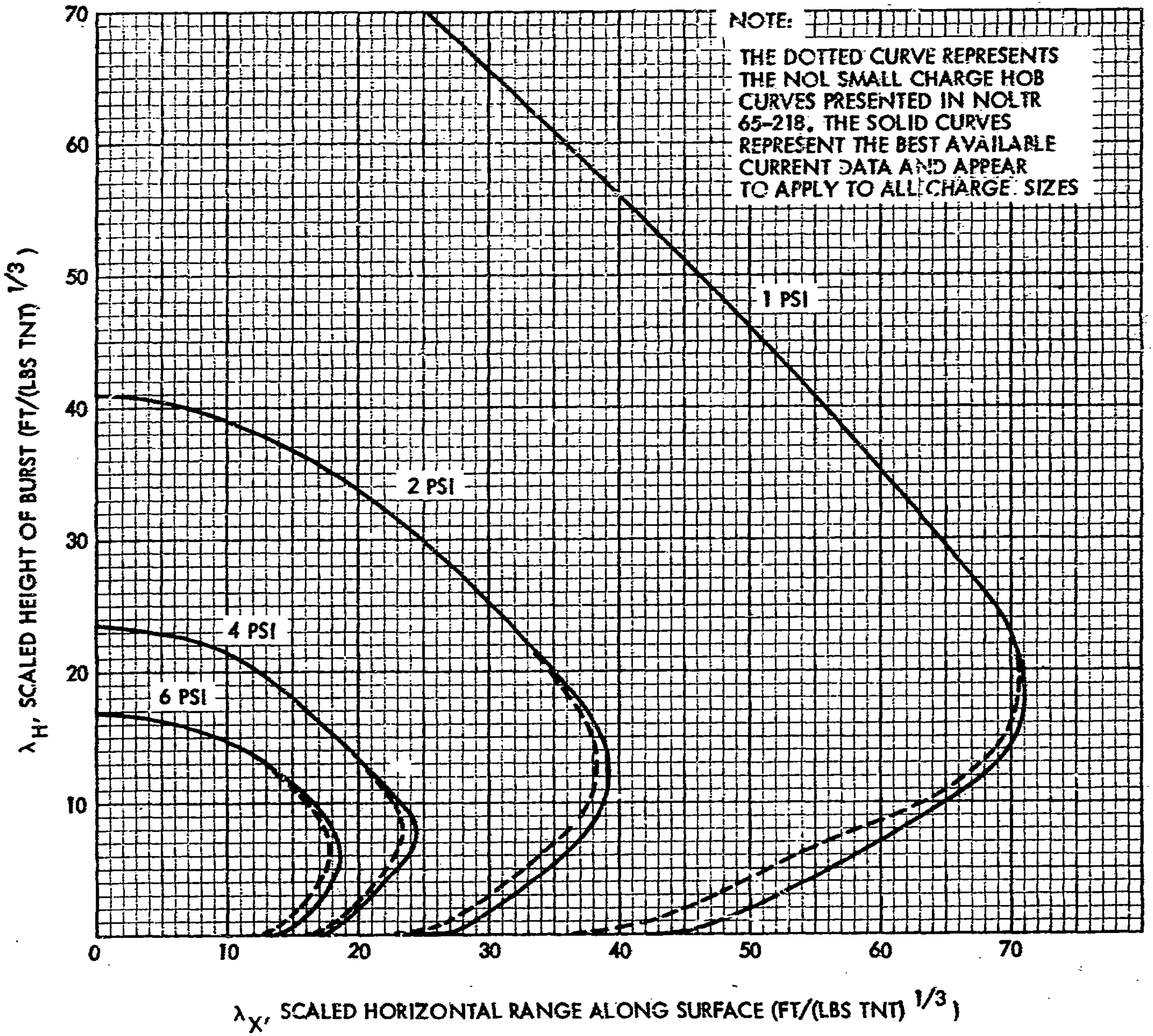


FIG. 5c HEIGHT OF BURST CURVES FOR PEAK OVERPRESSURE ON THE GROUND

CHAPTER 6

HEIGHT-OF-BURST CURVES--TIME OF ARRIVAL

Figure 6 gives the shock wave time of arrival along the ground surface as a function of the height-of-burst (HOB) and the horizontal range from ground zero for a scaled, one-pound TNT charge in a sea level atmosphere (14.7) psi). These curves are based on data contained in a private communication from BRL.

These curves are accurate to ± 10% in ground ranges for a given height-of-burst.

These curves may be scaled to other yields by the cube-root scaling equations presented in Chapter 1, and repeated here:

$$\frac{H}{H_1} = \frac{R}{R_1} = \frac{(W)^{1/3}}{(W_1)^{1/3}} = \frac{TOA}{TOA_1}$$

where H, R, and TOA are the height-of-burst, ground range, and time of arrival for 1 pound of TNT and H_1, R_1, and TOA_1 are the corresponding quantities for charge weight W_1 (pounds).

From Chapter 5:

$$\lambda_X = R\ (ft)/W\ (lb\ TNT)^{1/3}$$

$$\lambda_H = H\ (ft)/W\ (lb\ TNT)^{1/3}$$

For explosives other than TNT, first determine their TNT equivalence using Chapter 2, then use the above equations.

Problem Example 1

For a one-pound TNT charge detonated at a height-of-burst of 5 feet, what is the horizontal ground range for a shock time of arrival of 2 msec?

Solution

(a) For a λ_H = 5 ft/(lb TNT)$^{1/3}$, and a TOA of 2 msec, go to Figure 6

(b) From the 2 msec curve, for $\lambda_H = 5$ ft/(lb TNT)$^{1/3}$, read $\lambda_X = 3.0$ feet

(c) As stated above, the accuracy is ± 10% in ground range

∴(d) R = 3.0 feet ± 0.3 ft

Problem Example 2

For a 187-pound tritonal charge fired at an altitude of 20 feet, find the horizontal ground range for a time of arrival of 35.1 msec.

Solution

(a) From Figure 2i of Chapter 2, the average equivalent weight for tritonal is 0.96 for time of arrival. Then 208 pounds of tritonal are equivalent to 200 pounds of TNT (W_1 = 200 lb TNT)

(b) $W_1^{1/3} = 5.85$ (lb TNT)$^{1/3}$

(c) $\lambda_H = H/W_1^{1/3} = 20/5.85$

(d) $\lambda_H = 3.42$ ft/(lb TNT)$^{1/3}$

(e) $TOA = TOA_1/W_1^{1/3} = 35.1/5.85 = 6$ msec/(lb TNT)$^{1/3}$

(f) For a time of ar ival of 6 msec/(lb TNT)$^{1/3}$, go to Figure 6. For a $\lambda_H = 3.42$, and a TOA of 6, read $\lambda_X = 11.4$ ft/(lb TNT)$^{1/3}$

(g) $\lambda_X = R_1/W_1^{1/3}$, or $R_1 = \lambda_X \times W_1^{1/3}$

(h) $R_1 = 11.4$ ft(lb TNT)$^{1/3}$ X 5.85 (lb TNT)$^{1/3}$

$R_1 = 66.7$ feet

(i) accuracy is ± 10% in range

∴ $R_2 = 66.7$ feet ± 6.7 feet

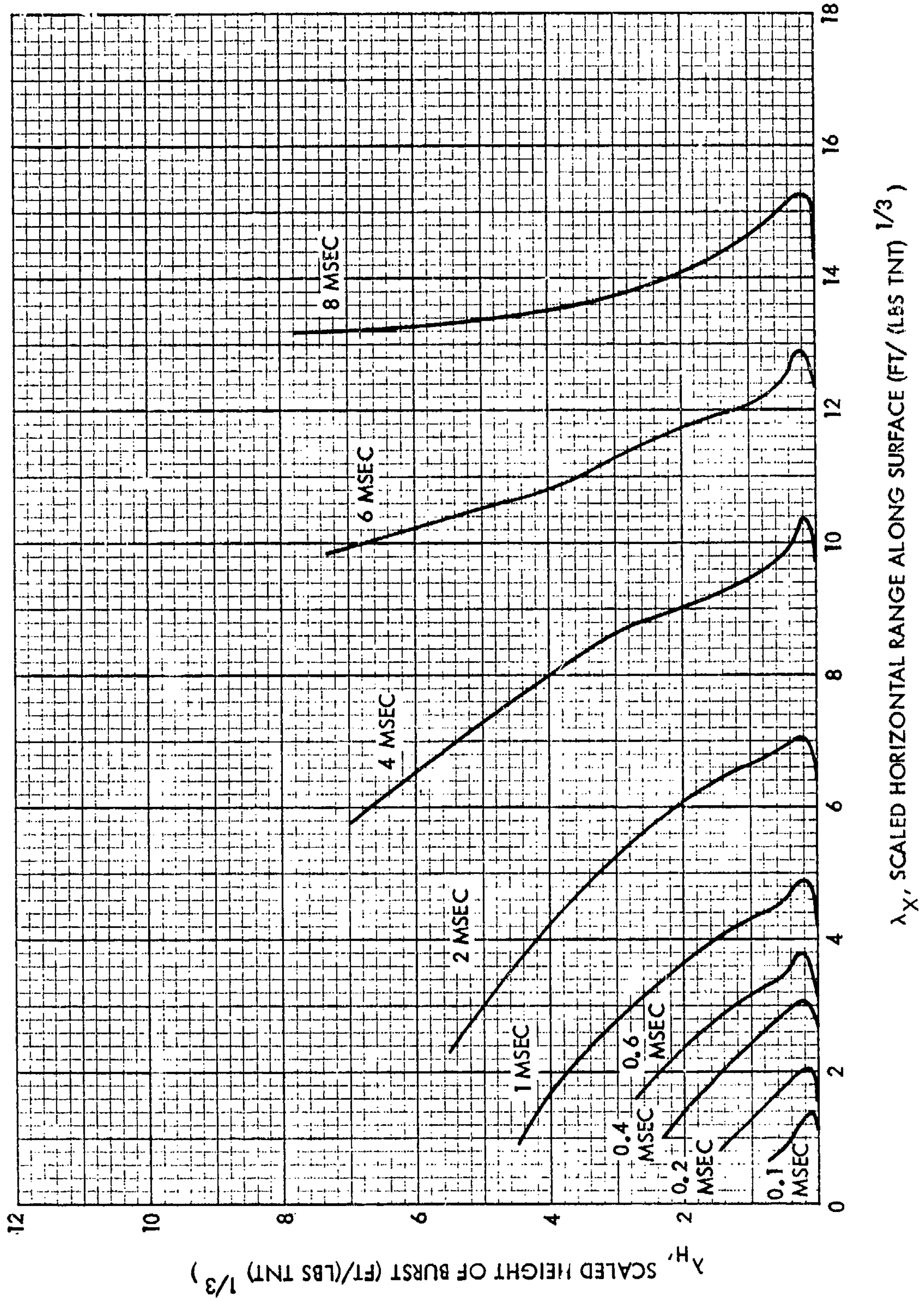


FIG. 6 HEIGHT OF BURST CURVES FOR TIME OF ARRIVAL ON THE GROUND

CHAPTER 7

HEIGHT-OF-BURST CURVES--POSITIVE DURATION

Figure 7 gives the shock wave positive duration along the ground surface as a function of the height-of-burst (HOB) and the horizontal range from ground zero for a scaled on-pound TNT charge in a sea level atmosphere (14.7 psi). These curves are based on data contained in a private communication from BRL.

These curves are accurate to ± 15% in ground range for a given height-of-burst.

These curves may be scaled to other yields by the cube-root scaling equations presented in Chapter 1, and repeated here:

$$\frac{H}{H_1} = \frac{R}{R_1} = \frac{(W)^{1/3}}{(W_1)^{1/3}} = \frac{\tau}{\tau_1}$$

where H, R, and τ are the height-of-burst, ground range, and positive duration for 1 pound of TNT and H_1 , R_1 , and τ_1 are the are the corresponding quantities for charge weight W_1 (pounds).

Remembering also that:

$$\lambda_X = R\ (\text{ft})/W\ (\text{lb TNT})^{1/3}$$

$$\lambda_H = H\ (\text{ft})/W\ (\text{lb TNT})^{1/3}$$

For explosives other than TNT, first determine their TNT equivalence using Chapter 2 , then use the above equations.

Problem Example 1

For a one-pound TNT charge detonated at a height-of-burst of 5 feet, what is the horizontal range for a shock duration of 1.5 msec

Solution

(a) For a λ_H = 5 ft/(lb TNT)$^{1/3}$ and a τ of 1.5 msec, use Figure 7

(b) From the 1.5 msec curve, for $\lambda_H = 5$ ft/(lb TNT)$^{1/3}$, read $\lambda_X = 2.6$ feet

(c) Accuracy is ± 15% in ground range
$\therefore R = 2.6$ feet ± .4 feet

Problem Example 2

For a 208-pound tritonal charge fired at an altitude of 20 feet, find the horizontal ground range for a duration of 11.7 msec.

Solution

(a) From Figure 21 of Chapter 2, the average equivalent weight for tritonal is 0.96 for duration. Then 208 pounds of tritonal are equivalent to 200 pounds of TNT ($W_1 = 200$ lb TNT)

(b) $W_1{}^{1/3} = 5.85$ (lb TNT)$^{1/3}$

(c) $\lambda_H = H/W_1{}^{1/3} = 20/5.85$

(d) $\lambda_H = 3.42$ ft/(lb TNT)$^{1/3}$

(e) $\tau_1 = \tau_1/W_1{}^{1/3} = 11.7/5.85 = 2$ msec/(lb TNT)$^{1/3}$

(f) For $\tau = 2$ msec/(lb TNT)$^{1/3}$, use Figure 7
For $\tau_H = 3.42$ ft, and $T = 2$ msec, Read
$\lambda_X = 7$ ft/(lb TNT)$^{1/3}$

(g) $R_1 = \lambda_X \times W_1{}^{1/3} = 7$ ft/(lb TNT)$^{1/3}$ X 5.85 (lb TNT)$^{1/3}$
$R_1 = 41.0$ ft

(h) Accuracy is ± 15% in ground range
$\therefore R_1 = 41.0$ feet ± 6.1 feet

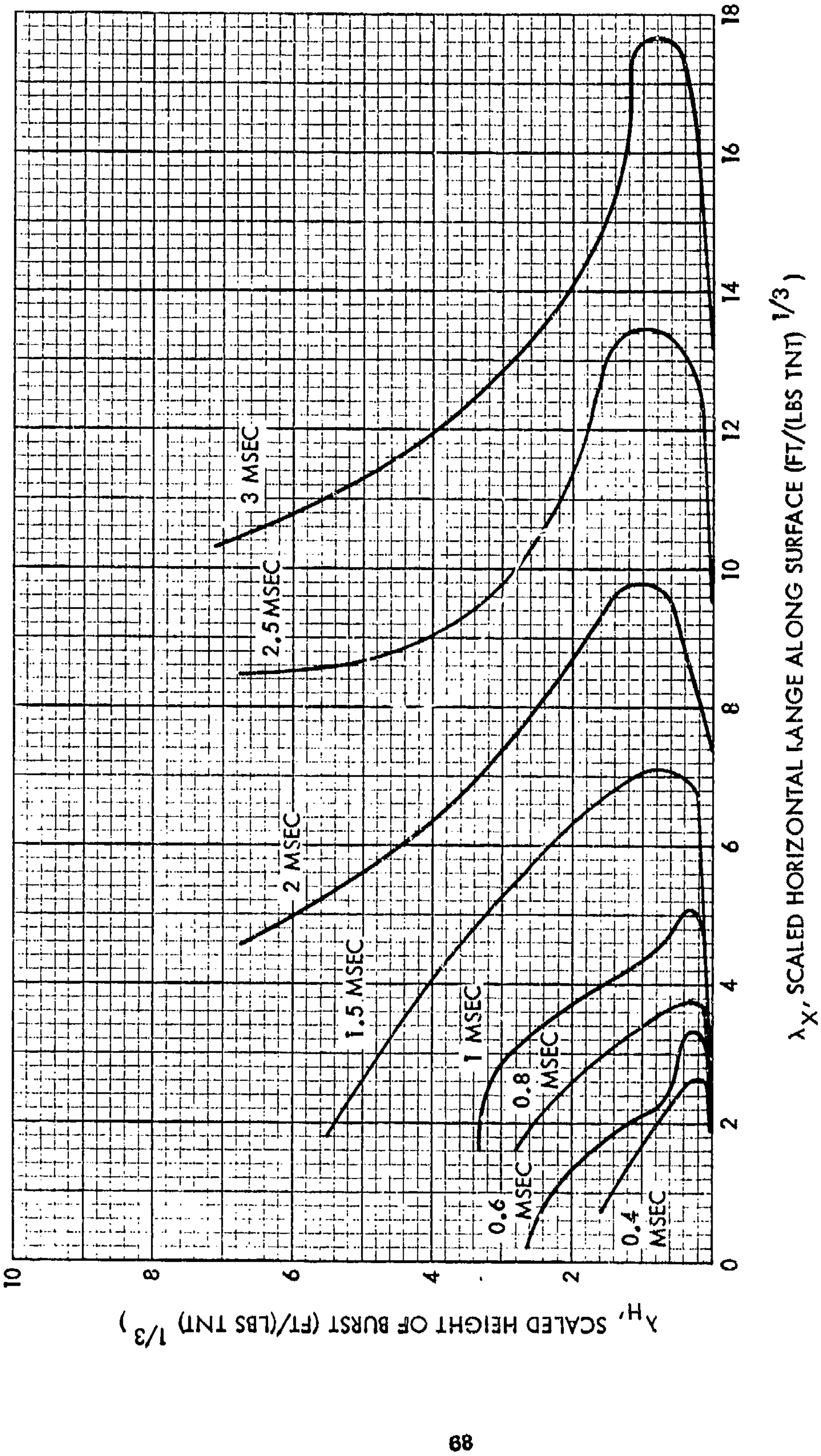


FIG. 7 HEIGHT OF BURST CURVES FOR POSITIVE DURATION ON THE GROUND

CHAPTER 8

HEIGHT-OF-BURST CURVES--POSITIVE IMPULSE

Figure 8 gives the shock wave positive impulse along the ground surface as a function of the height-of-burst (HOB) and the horizontal range from ground zero for a scaled one-pound TNT charge in a sea level atmosphere (14.7 psi). These curves are based on data contained in a private communication from BRL.

Thse curves are accurate to ± 15% in ground range for a given height-of-burst.

These curves may be scaled to other yields by the cube-root scaling equations presented in Chapter 1, and repeated here:

$$\frac{H}{H_1} = \frac{R}{R_1} = \frac{(W\ )^{1/3}}{(W_1)^{1/3}} = \frac{I}{I_1}$$

where H, R, and I are the height-of-burst, ground range, and positive impulse for one pound of TNT and H_1, R_1, and I_1 are the corresponding quantities for charge weight W_1.

Remembering also that

$$\lambda_X = R\ (\mathrm{ft})/W\ (\mathrm{lb\ TNT})^{1/3}$$

$$\lambda_H = H\ (\mathrm{ft})/W\ (\mathrm{lb\ TNT})^{1/3}$$

For explosives other than TNT, first determine their TNT equivalence using Chapter 2 , then use the above equations.

Problem Example 1

For a one-pound TNT charge detonated at a height-of-burst of 5 feet, what is the horizontal range for a positive impulse of 10 psi-msec?

Solution

(a) For λ_H = 5 ft/(lb TNT)$^{1/3}$, and I = 10 psi-msec, use Figure 8

(b) From the 10 psi-msec curve, for $\lambda_H = 5$, read
$\lambda_X = 10.1$ feet

(c) Accuracy is ± 15% in ground range
$\therefore R = 10.1$ feet ± 1.5 feet

Problem Example 2

For a 208-pound tritonal charge fired at an altitude of 20 feet, find the horizontal ground range for a positive impulse of 146.3 psi-msec.

Solution

(a) From Figure 21 of Chapter 2, the average equivalent weight for tritonal is 0.96 for impulse. Then 208 pounds of tritonal are equivalent to 200 pounds of TNT ($W_1 = 200$ lb TNT)

(b) $W_1^{1/3} = 5.85 \text{ (lb TNT)}^{1/3}$

(c) $\lambda_H = H/W_1^{1/3} = 20/5.85$

(d) $\lambda_H = 3.42 \text{ ft/(lb TNT)}^{1/3}$

(e) $I = I_1/W_1^{1/3} = 1.46.3/5.85 = 25 \text{ psi-msec/(lb TNT)}^{1/3}$

(f) For $I = \text{psi-msec/(lb TNT)}^{1/3}$ use Figure 8
For $\lambda_H = 3.42 \text{ ft/(lb TNT)}^{1/3}$ and $I = 25 \text{ psi msec/(lb TNT)}^{1/3}$,
Read $\lambda_X = 3.3 \text{ ft/(lb TNT)}^{1/3}$

(g) $R_1 = \lambda_X \times W_2^{1/3} = 3.3 \text{ ft/(lb TNT)}^{1/3} \times 5.85 \text{ (lb TNT)}^{1/3}$
$R_1 = 19.3$ feet

(h) Accuracy is ± 15% in ground range
$\therefore R_1 = 19.3$ feet ± 2.9 feet

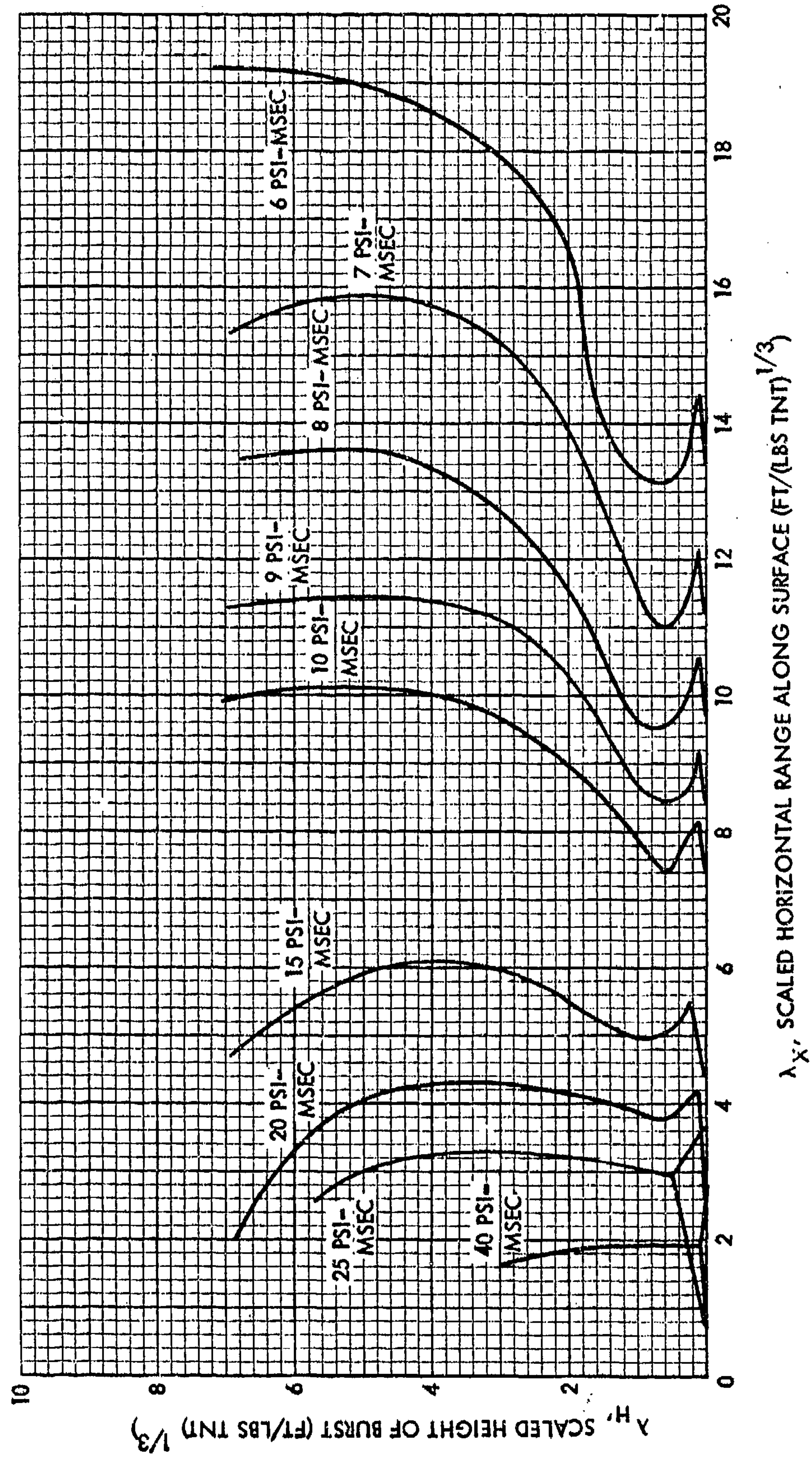


FIG. 8 HEIGHT OF BURST CURVES FOR POSITIVE IMPULSE ON THE GROUND

CHAPTER 9

AIRBLAST AT VARIOUS ALTITUDES ABOVE SEA LEVEL

This chapter presents altitude correction factors for converting blast effects from any charge in a standard sea level atmosphere to the same charge at any altitude of interest up to 100,000 feet using the profiles given in U.S. Standard Atmosphere of 1962. In addition scaled pressure versus scaled distance curves are presented for various altitudes (Figures 19c and 19d).

$$\Delta P_z = \Delta P_o \; S_p \tag{1}$$

$$\Delta Q_z = \Delta Q_o \; S_p \tag{2}$$

$$\Delta P_{r,z} = \Delta P_{r,o} \; S_p \tag{3}$$

$$\lambda_z = \lambda_o \; S_d \tag{4}$$

$$TOA_z = t_o \; S_t \tag{5}$$

$$\tau_z = \tau_o \; S_t \tag{6}$$

$$I_z = I_o \; S_I \tag{7}$$

The subscript, z, refers to the parameter at altitude, z, and the subscript, o, refers to the parameter at sea level

ΔP	overpressure (psi)
ΔQ	dynamic pressure (psi)
ΔP_r	reflected pressure (psi)
λ	scaled distance (ft)
TOA	time of arrival (msec)
τ	positive duration (msec)
I	positive impulse (psi-msec)
S_p	altitude correction factor for pressure
S_d	altitude correction factor for distance
S_t	altitude correction factor for time
S_I	altitude correction factor for impulse

The altitude scaling equations listed below are valid for equal yields at sea level and at altitude z.

$$S_p = (P_z/P_o) \tag{8}$$

$$S_d = (P_o/P_z)^{1/3} \tag{9}$$

$$S_t = (P_o/P_z)^{1/3} \text{ X} \left(\frac{T_o}{T_z}\right)^{1/2} \tag{10}$$

$$S_I = (P_z/P_o)^{2/3} \text{ X} \left(\frac{T_o}{T_z}\right)^{1/2} \tag{11}$$

where P_o = atmospheric pressure in psi at sea level, 14.7 psi
P_z = atmospheric pressure in psi at altitude, z
T_o = atmospheric temperature in °K at sea level = 288.16 °K
T_z = atmopsheric temperature in °K at altitude, z

Problem Example

For a one-pound TNT charge fired in a standard sea level atmosphere, the airblast parameters have the following values at a distance of 8 feet from the charge:

λ_o = 8 feet
P_o = 9.1 psi
$\Delta P_{r,o}$ = 22.6 psi
TOA_o = 6.65 msec
τ_o = 1.88 msec
I_o = 6.05 psi-msec

What are the values of these parameters at a distance of 8 feet from a one-pound charge fired at 50,000 feet?

Solution

(a) From Figure 9b, the altitude correction factor for distance S_d, at 50,000 feet is 2.056. Therefore, the distance at sea level that corresponds to 8 feet at an altitude of 50,000 feet is 8/2.056 = 3.89 feet ($\lambda_o = \lambda_z/S_d$ from equation 4).

(b) From Figure 3a or 3c, the sea level peak overpressure at 3.89 feet is 50 psi. The altitude correction factor for pressure at 50,000 feet is 0.115.

$$\Delta P_z = 50 \times 0.115 = 5.7 \text{ psi}$$

$$(\Delta P_z = \Delta P_o S_p)$$

(c) From Figure 12b, the peak reflected pressure for 50.0 psi at sea level is 198.3 psi. The altitude correction factor is .115.

$$\Delta P_{r,z} = .115 \times 198.3 = 22.8 \text{ psi}$$

$$(\Delta P_{r,z} = \Delta P_{r,o} S_p)$$

(d) From Figure 3a or 3c, the shock arrival time at 3.89 feet is 1.70 msec. The altitude correction factor for time at 50,000 feet is 2.370.

$$TOA_z = 1.70 \times 2.37 = 4.03 \text{ msec}$$

$$(TOA_z = t_o S_t)$$

(e) From Figure 3a or 3c, the positive duration at 3.89 feet is 1.40 msec. The altitude correction factor for time is 2.37 at 50,000 feet.

$$\tau_z = 1.40 \times 2.37 = 3.32 \text{ msec}$$

$$(\tau_z = \tau_o S_t)$$

(f) From Figure 3a or 3c, the impulse at 3.89 feet is 12.54 psi-msec. The altitude correction factor for impulse is .273 at 50,000 feet.

$$I_z = 12.54 \times .273 = 3.42 \text{ psi-msec}$$

$$(I_z = I_o S_I)$$

In summary:

λ_z = 8 feet

ΔP_z = 5.7 psi

$\Delta P_{r,z}$ = 22.8 psi

TOA_z = 4.03 msec

τ_z = 3.32 msec

I_z = 3.42 psi-msec

Alternative Solution

An alternative solution for the airblast pressure can be obtained using Figure 9c.

At a λ_z = 8 ft/(lb TNT)$^{1/3}$, read a ΔP_z of 6 psi.

Reference:

Sachs, R. G., "The Dependence of Blast on Ambient Pressure and Temperature," Ballistics Research Laboratories Report No. 466, May 1944, Unclassified

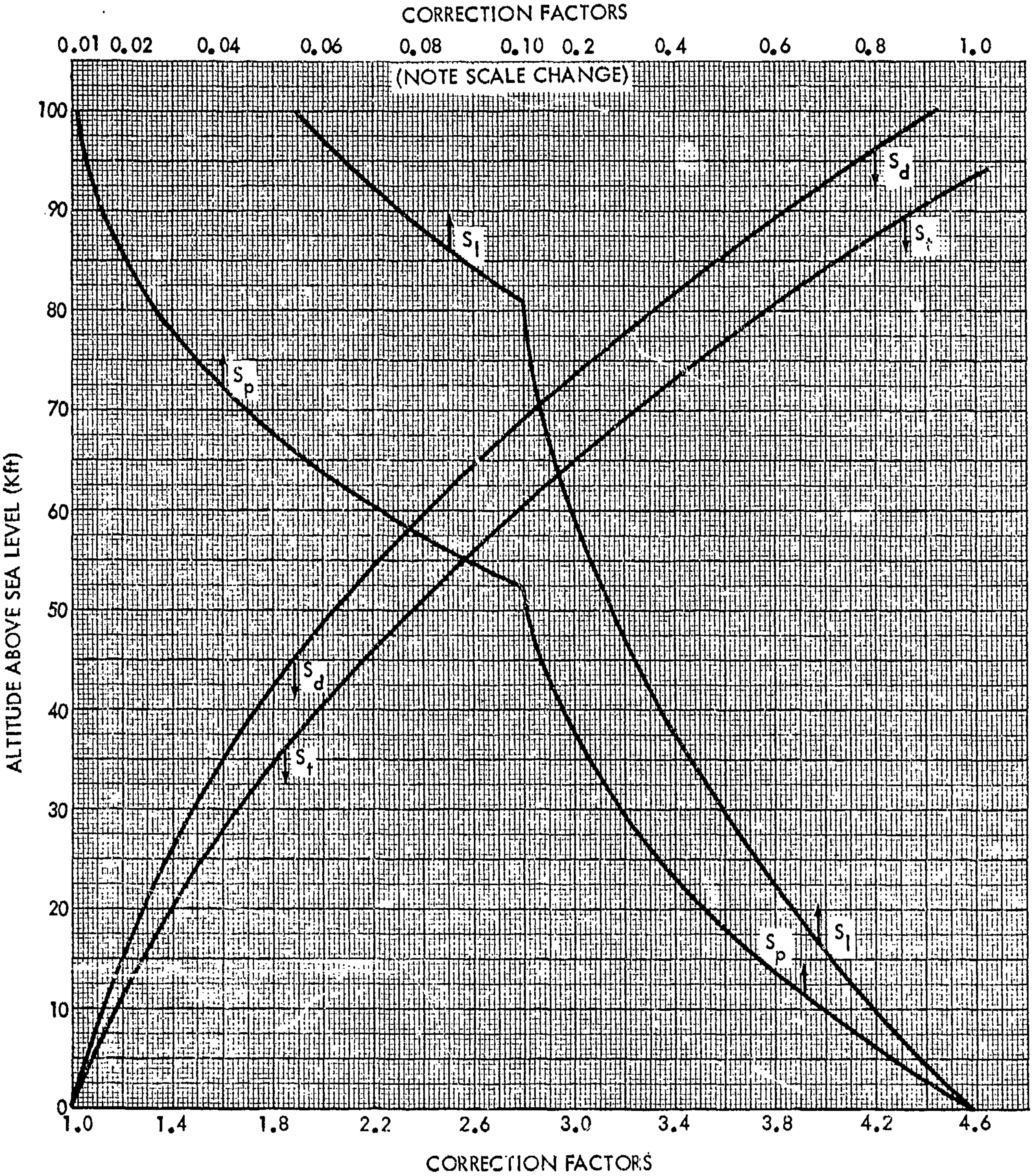


FIG. 9a ALTITUDE CORRECTION FACTORS VS ALTITUDE ABOVE SEA LEVEL

Alternative Solution

An alternative solution for the airblast pressure can be obtained using Figure 9c.

At a $\lambda_z = 8$ ft/(lb TNT)$^{1/3}$, read a ΔP_z of 6 psi.

Reference:

Sachs, R. G., "The Dependence of Blast on Ambient Pressure and Temperature," Ballistics Research Laboratories Report No. 466, May 1944, Unclassified

ALTITUDE (Kft)	AMB. PRESS. (psi)	PRESSURE S_p	DISTANCE S_d	TIMES S_t	IMPULSE S_I
0	14.7	1.00000	1.0000	1.0000	1.00000
2	13.668	.92982	1.02455	1.03167	.95926
4	12.696	.86369	1.05006	1.06480	.91965
6	11.781	.80143	1.07658	1.09949	.88116
8	10.920	.74287	1.10415	1.13582	.84377
10	10.111	.68783	1.13285	1.17390	.80745
12	9.351	.63615	1.16273	1.21385	.77220
14	8.639	.58768	1.19386	1.25579	.73799
16	7.971	.54224	1.22632	1.29984	.70482
18	7.346	.49970	1.26017	1.34614	.67267
20	6.761	.45991	1.29551	1.39486	.64151
22	6.214	.42274	1.33243	1.44615	.61134
24	5.704	.38804	1.37102	1.50021	.58214
26	5.229	.35569	1.41138	1.55722	.55388
28	4.786	.32556	1.45363	1.61740	.52657
30	4.374	.29754	1.49790	1.68098	.50017
32	3.991	.27152	1.54431	1.74822	.47467
34	3.636	.24737	1.59302	1.81941	.45006
36	3.307	.22499	1.64417	1.89484	.42632
38	3.005	.20444	1.69751	1.95767	.40022
40	2.731	.18577	1.75257	2.02117	.37547
42	2.481	.16881	1.80941	2.08672	.35225
44	2.255	.15340	1.86808	2.15438	.33047
46	2.049	.13935	1.92864	2.22422	.31005
48	1.862	.12667	1.99115	2.29632	.29088
50	1.692	.11512	2.05568	2.37073	.27291
52	1.538	.10461	2.12228	2.44755	.25605
54	1.398	.09507	2.19103	2.52683	.24023
56	1.270	.08640	2.26199	2.60867	.22539
58	1.154	.07852	2.33524	2.69314	.21148
60	1.049	.07137	2.41084	2.78033	.19842
62	.953	.06486	2.48888	2.87032	.18618
64	.867	.05895	2.56942	2.96321	.17469
66	.788	.05358	2.65256	3.05872	.16388
68	.716	.04871	2.73822	3.15309	.15358
70	.651	.04429	2.82639	3.25009	.14395

FIG. 9.b ALTITUDE CORRECTION FACTORS

ALTITUDE (Kft)	AMB. PRESS. (psi)	PRESSURE S_p	DISTANCE S_d	TIMES S_t	IMPULSE S_I
72	.592	.04028	2.91712	3.34978	.13494
74	.539	.03665	3.01048	3.45221	.12653
76	.490	.03336	3.10654	3.55745	.11866
78	.446	.03036	3.20537	3.66558	.11130
80	.406	.02765	3.30704	3.77667	.10442
82	.370	.02518	3.41163	3.89078	.09798
84	.337	.02294	3.51920	4.00800	.09196
86	.307	.02091	3.62983	4.12839	.08632
88	.280	.01906	3.74361	4.25202	.08104
90	.255	.01738	3.86061	4.37899	.07610
92	.233	.01585	3.98092	4.50937	.07148
94	.213	.01446	4.10460	4.64323	.06714
96	.194	.01320	4.23176	4.78069	.06309
98	.177	.01204	4.36248	4.92176	.05928
100	.162	.01100	4.49684	5.06659	.05572

FIG. 9 b ALTITUDE CORRECTION FACTORS (Continued)

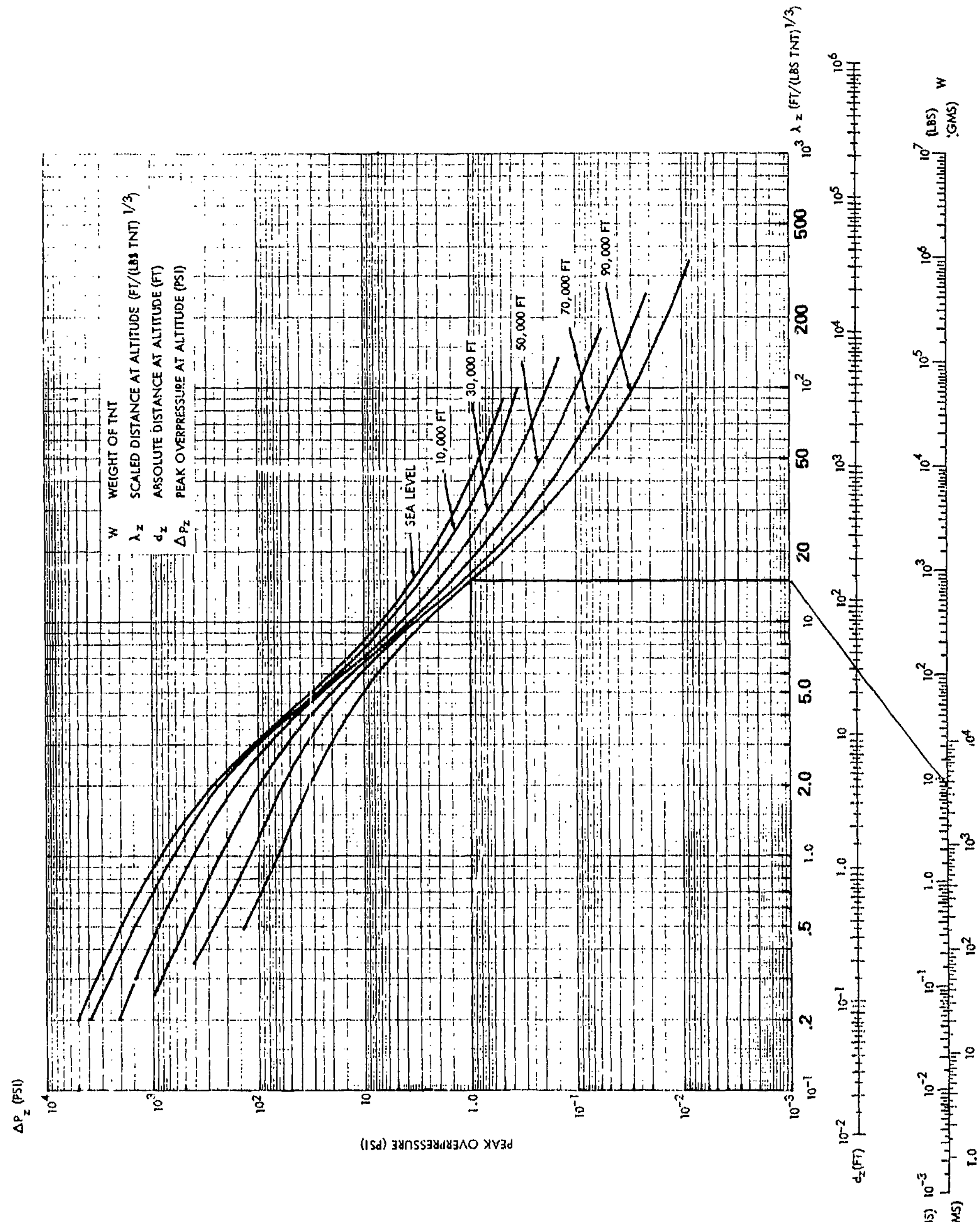


FIG. 9c FREE AIR PEAK OVERPRESSURE VERSUS DISTANCE AT VARIOUS ALTITUDES (SEA LEVEL TO 90,000 FEET)

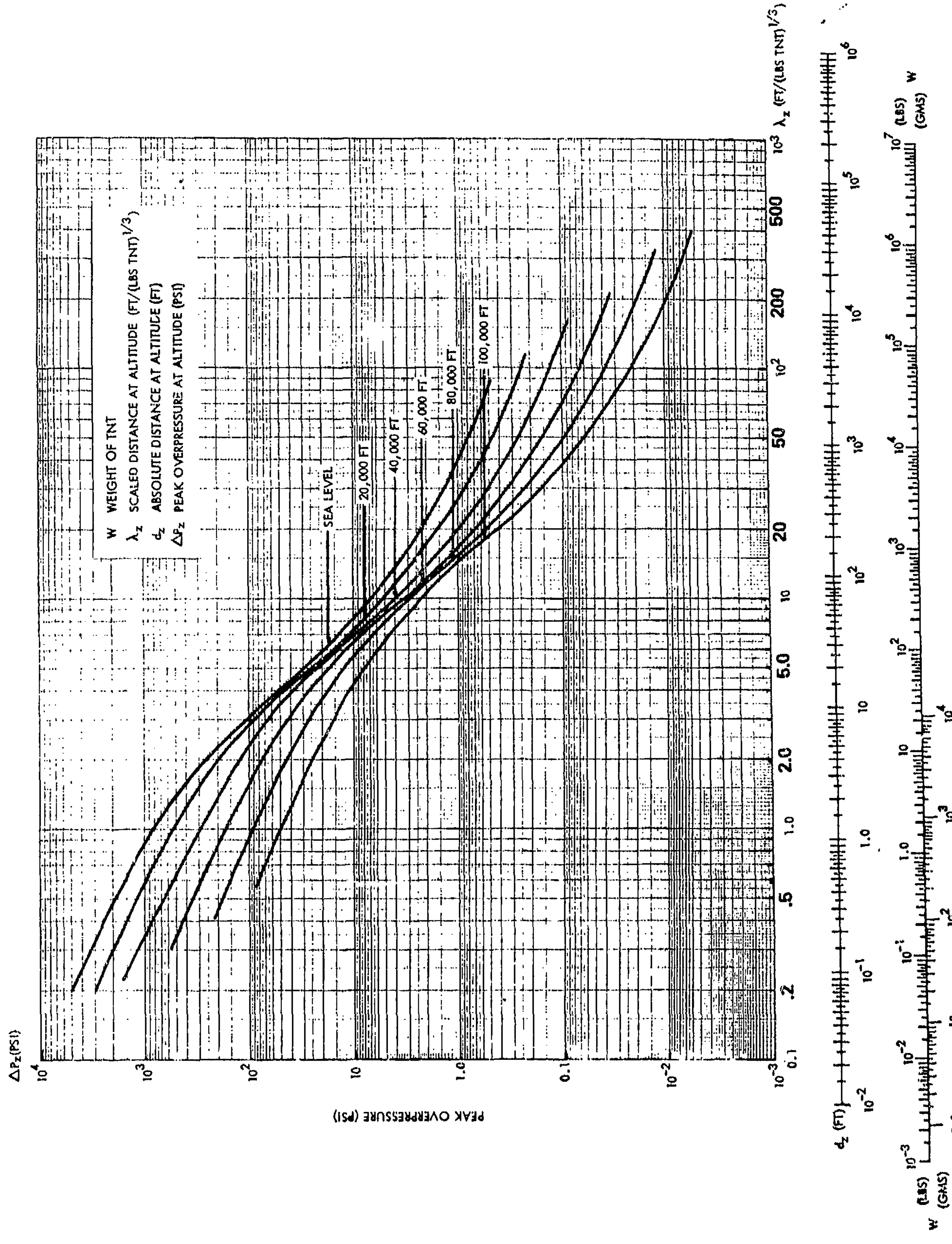


FIG. 9d FREE AIR PEAK OVERPRESSURE VERSUS DISTANCE AT VARIOUS ALTITUDES (SEA LEVEL TO 100,000 FEET)

CHAPTER 10

PEAK OVERPRESSURE AND POSITIVE IMPULSE VS SCALED DISTANCE FOR SPHERES AND HEMISPHERES DETONATED ON THE SURFACE

Peak overpressure and positive impulse for spheres and hemispheres are presented in this Chapter. The dashed curves are for spherical TNT charges which are tangent to the ground surface. The solid curves are for hemispherical charges on the ground surface. That is, the two geometries are as follows:

These configurations are often used in large-scale nuclear weapon blast simulation tests. The curves (and tables)--both for pressure and for impulse--are composite curves, based on many experiments. The peak pressures are valid within ± 10%, while the impulses are good to ± 15%.

Problem Example

Compare the pressures and impulses generated by 1000-pound spheres and hemispheres of TNT at a distance of 80 feet.

Solution

(a) $\lambda_x = R/W^{1/3} = 80/(1000)^{1/3} = 8 \text{ ft/lb}^{1/3}$

(b) At this λ_x, read $P_s = 17$ psi, $P_{hs} = 14.5$ psi from Figure 10a and $I_s = 9.4$ psi-msec and $I_{hs} = 9.8$ psi-msec from Figures 10b

(Subscripts s and hs refer to sphere and hemisphere, respectively)

(c) For 1000 pounds $I_s = 9.4 \times (1000)^{1/3} = 94$ psi-msec

$I_{hs} = 9.8 \times (1000)^{1/3} = 98$ psi-msec

Alternative Solution: Refer to Figure 10d for 1000 pounds of TNT and read directly $P_s = 17.5$ psi

$P_{hs} = 15.0$ psi, $I_s = 93.6$ psi, msec,

$I_{hs} = 98.5$ psi-msec

The hemispherical data are based on a compendium made by Kingery and Pannil. The spherical charge curves are based, with some refinements, on a new compendium of data first appearing in NOLTR 73-105 (see references).

References:

(1) Kingery, C. N. and Pannil, B. F., "Peak Overpressure vs Scaled Distance for TNT Surface Bursts (Hemispherical Charges)," BRL-MR-1508, Apr 1964

(2) Kingery, C. N., "Air Blast Parameters vs Distance for Hemispherical TNT Surface Bursts," BRL Report 1344, Sep 1966

(3) Sadwin, L. D. and Swisdak, M. M., Jr., "Performance of Multiton AN/FO Detonations, A Summary Report," NOLTR 73-105, 2 Jul 1973

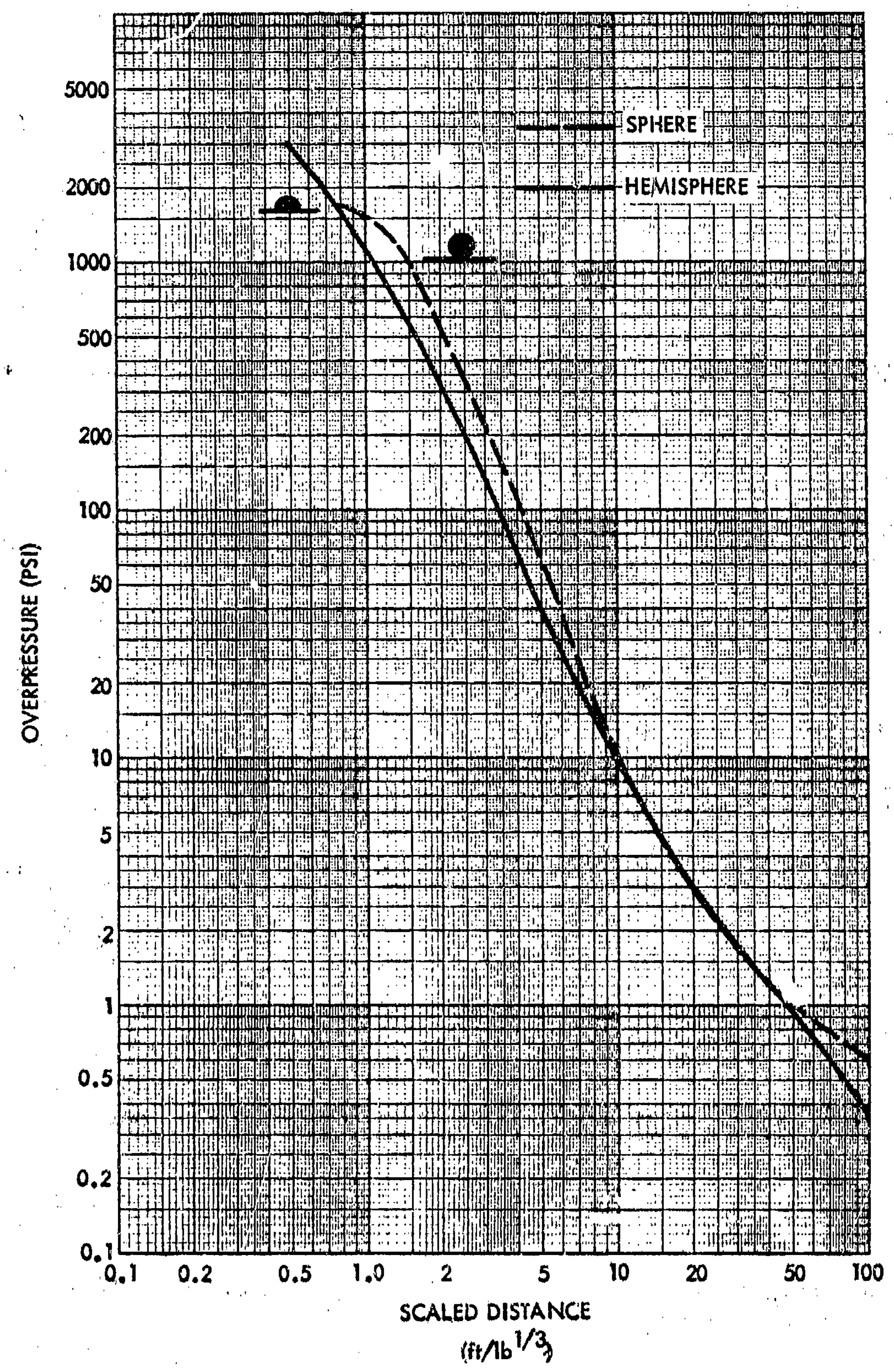


FIG. 10a PEAK PRESSURE VS SCALED DISTANCE FOR SPHERES AND HEMISPHERES OF TNT DETONATED ON THE SURFACE

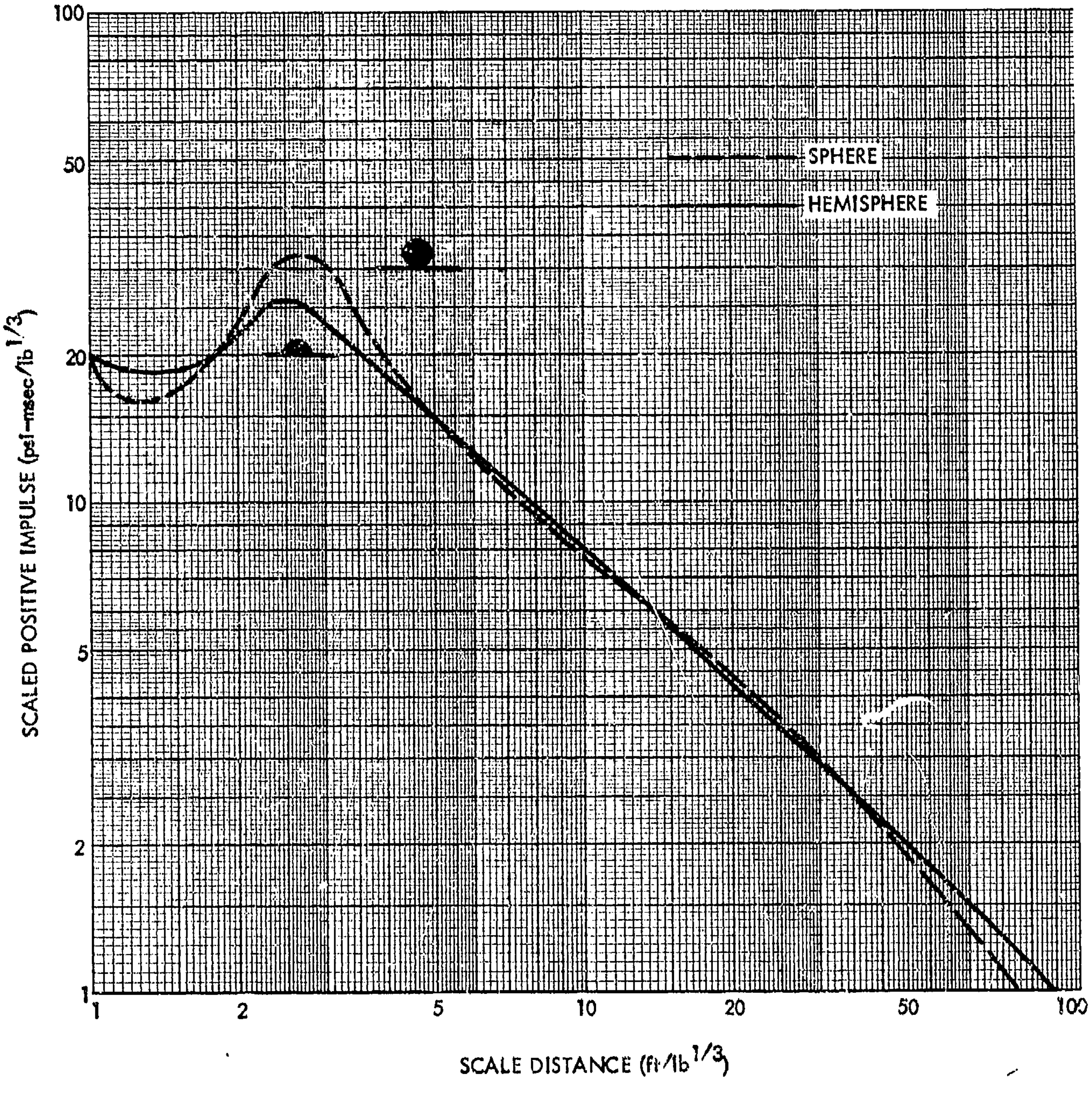


FIG. 10b POSITIVE IMPULSE VS SCALED DISTANCE FOR SPHERES AND HEMISPHERES OF TNT DETONATED ON THE SURFACE

	Sphere	Hemisphere	Sphere	Hemisphere
Scaled Distance	Peak Pressure	Peak Pressure	Positive Impulse	Positive Impulse
(feet)	(psi)	(psi)	(psi-msec)	(psi-msec)
0.8	1605	1629		
1.0	1538	1147	20.39	20.00
1.25	1258	786.5	16.49	18.7
1.50	972.7	564.8	17.1	18.6
1.75	738.6	419.7	19.02	19.6
2.00	560.2	320.7	23.28	22.4
2.25	448.8	250.8	28.90	24.7
2.50	337.4	200.0	31.3	26.4
2.75	276.4	162.3	31.8	25.4
3.00	215.3	133.7	31.0	23.9
3.50	144.9	94.4	24.8	21.1
4.00	102.3	69.6	20.1	18.5
4.50	75.1	53.2	17.05	16.6
5.00	57.0	41.8	14.9	15.1
6.00	35.6	27.3	12.2	12.8
7.00	24.2	19.9	10.5	11.1
8.00	17.5	15.0	9.36	9.85
9.00	13.3	11.8	8.48	8.90
10.00	10.5	9.61	7.79	8.10
15.00	4.61	4.67	5.65	5.65
20.00	2.84	2.98	4.43	4.30
25.00	2.07	2.18	3.59	3.48
30.00	1.65	1.71	2.98	2.93
40.00	1.22	1.18	2.16	2.21
50.00	1.01	0.89	1.64	1.79
75.00	0.74	0.52	0.98	1.20
100.00	0.59	0.35	0.66	0.90

FIG. 10c ONE POUND OF TNT

Distance (Feet)		Sphere Peak Pressure (psi)	Hemisphere Peak Pressure (psi)		Sphere Positive Impulse (psi-msec)	Hemisphere Positive Impulse (psi-msec)
8.0		1605.0	1629.0			
10.0		1538.0	1147.0		203.9	200.0
12.5		1258.0	786.5		164.9	187.0
15.0		972.7	564.8		171.0	186.0
17.5		738.6	419.7		190.2	196.0
20.0		560.2	320.7		232.8	224.0
22.5		448.8	250.8		289.0	247.0
25.0		337.4	200.0		313.0	264.0
27.5		276.4	162.3		318.0	254.0
30.0		215.3	133.7		310.0	239.0
35.0		144.9	94.4		248.0	211.0
40.0		102.3	69.6		201.0	185.0
45.0		75.1	53.2		170.5	166.0
50.0		57.0	41.8		149.0	151.0
60.0		35.6	27.8		122.0	128.0
70.0		24.2	19.9		105.0	111.1
80.0		17.5	15.0		93.6	98.5
90.0		13.3	11.8		94.8	89.0
100.0		10.5	9.61		77.9	81.0
150.0		4.61	4.67		56.5	56.5
200.0		2.84	2.98		44.3	43.0
250.0		2.07	2.18		35.9	34.8
300.0		1.65	1.71		29.8	29.3
400.0		1.22	1.18		21.6	22.1
500.0		1.01	0.89		16.4	17.9
750.0		0.74	0.52		9.8	12.0
1000.0		0.59	0.35		6.6	9.0

FIG. 10d ONE THOUSAND POUNDS OF TNT

Distance (Feet)	Sphere Peak Pressure (psi)	Hemisphere Peak Pressure (psi)	Sphere Positive Impulse (psi-msec)	Hemisphere Positive Impulse (psi-msec)
13.7	1605.0	1629.0		
17.1	1538.0	1147.0	348.6	342.0
21.4	1258.0	786.5	282.0	319.8
25.6	972.7	564.8	292.4	318.1
29.9	738.6	419.7	325.2	335.2
34.2	560.2	320.7	398.1	383.0
38.5	448.8	250.8	494.2	422.4
42.7	337.4	200.0	535.2	451.4
47.0	276.4	162.3	543.8	434.3
51.3	215.3	133.7	530.1	408.7
59.8	144.9	94.4	424.1	360.8
68.4	102.3	69.6	343.7	316.3
76.9	75.1	53.2	291.6	283.9
85.5	57.0	41.8	254.8	258.2
102.6	35.6	27.8	208.6	218.9
119.7	24.2	19.9	179.5	189.8
136.8	17.5	15.0	160.1	168.4
153.9	13.3	11.8	145.0	152.2
171.0	10.5	9.61	133.2	138.5
256.5	4.61	4.67	96.6	96.6
342.0	2.84	2.98	75.8	73.5
427.5	2.07	2.18	61.4	59.5
513.0	1.65	1.71	51.0	50.1
684.0	1.22	1.18	36.9	37.8
855.0	1.01	0.89	28.0	30.6
1282.0	0.74	0.52	16.8	20.5
1710.0	0.59	0.35	11.3	15.4

FIG. 10e FIVE THOUSAND POUNDS OF TNT

Distance (Feet)	Sphere Peak Pressure (p[illegible]i)	Hemisphere Peak Pressure (psi)	Sphere Positive Impulse (psi-msec)	Hemisphere Positive Impulse (psi-msec)
17.2	1605.0	1629.0		
21.5	1538.0	1147.0	439.3	430.9
26.9	1258.0	786.5	355.3	402.9
32.3	972.7	564.8	368.4	400.7
37.7	738.6	419.7	409.8	422.3
43.1	560.2	320.7	501.6	482.6
48.5	448.8	250.8	622.6	532.1
53.9	337.4	200.0	674.3	568.8
59.2	276.4	162.3	685.1	547.2
64.6	215.3	133.7	667.9	514.9
75.4	144.9	94.4	534.3	454.6
86.2	102.3	69.6	433.0	398.6
96.9	75.1	53.2	367.3	357.6
107.7	57.0	41.8	321.0	325.3
129.3	35.6	27.8	262.8	275.8
150.8	24.2	19.9	226.2	239.1
172.3	17.5	15.0	201.7	212.2
193.8	13.3	11.8	182.7	191.7
215.4	10.5	9.61	167.8	174.5
323.2	4.61	4.67	121.7	121.7
430.9	2.84	2.98	95.4	92.6
538.6	2.07	2.18	77.3	75.0
646.3	1.65	1.71	64.2	63.1
861.8	1.22	1.18	46.5	47.6
1077.0	1.01	0.89	35.3	38.6
1616.0	0.74	0.52	21.1	25.9
2154.0	0.59	0.35	14.2	19.4

FIG. 10f TEN THOUSAND POUNDS OF TNT

Distance (Feet)	Sphere Peak Pressure (psi)	Hemisphere Peak Pressure (psi)	Sphere Positive Impulse (psi-msec)	Hemisphere Positive Impulse (psi-msec)
27.4	1605.0	1629.0		
34.2	1538.0	1147.0	697.3	684.0
42.7	1258.0	786.5	564.0	639.5
51.3	972.7	564.8	584.8	636.1
59.8	738.6	419.7	650.5	670.3
68.4	560.2	320.7	796.2	766.1
76.9	448.8	250.8	988.4	844.7
85.5	337.4	200.0	1070.0	902.9
94.0	276.4	162.3	1088.0	868.7
102.6	215.3	133.7	1060.0	817.4
119.7	144.9	94.4	848.1	721.6
136.8	102.3	69.6	687.4	632.7
153.9	75.1	53.2	583.1	567.7
171.0	57.0	41.8	509.6	516.4
205.2	35.6	27.8	417.2	437.8
239.4	24.2	19.9	359.1	379.6
273.6	17.5	15.0	320.1	336.9
307.8	13.3	11.8	290.0	304.4
342.0	10.5	9.61	266.4	277.0
513.0	4.61	4.67	193.2	193.2
684.0	2.84	2.98	151.5	147.1
855.0	2.07	2.18	122.8	119.0
1026.0	1.65	1.71	101.9	100.2
1368.0	1.22	1.18	73.9	75.6
1710.0	1.01	0.89	56.1	61.2
2565.0	0.74	0.52	33.5	41.0
3420.0	0.59	0.35	22.6	30.8

FIG. 10g TWENTY TONS - FORTY THOUSAND POUNDS OF TNT

Distance (Feet)		Sphere Peak Pressure (psi)	Hemisphere Peak Pressure (psi)		Sphere Positive Impulse (psi-msec)	Hemisphere Positive Impulse (psi-msec)
37.1		1605.0	1629.0			
46.4		1538.0	1147.0		946.4	928.3
58.0		1258.0	786.5		765.4	867.9
69.6		972.7	564.8		793.7	863.3
81.2		738.6	419.7		882.8	909.6
92.8		560.2	320.7		1080.0	1040.0
104.4		448.8	250.8		1341.0	1146.0
116.0		337.4	200.0		1453.0	1225.0
127.6		276.4	162.3		1476.0	1179.0
139.2		215.3	133.7		1439.0	1109.0
162.5		144.9	94.4		1151.0	979.4
185.7		102.3	69.6		933.0	858.7
208.8		75.1	53.2		791.4	770.5
232.1		57.0	41.8		691.6	700.8
278.5		35.6	27.8		566.3	594.1
394.9		24.2	19.9		487.4	515.2
371.3		17.5	15.0		434.5	457.2
417.7		13.3	11.8		393.6	413.1
464.2		10.5	9.61		361.6	376.0
696.2		4.61	4.67		262.2	262.2
928.3		2.84	2.98		205.6	199.6
1160.0		2.07	2.18		166.6	161.5
1392.0		1.65	1.71		138.3	136.0
1857.0		1.22	1.18		100.3	102.6
2321.0		1.01	0.89		76.1	83.1
3481.0		0.74	0.52		45.5	55.7
4642.0		0.59	0.35		30.6	41.8

FIG. 10h FIFTY TONS - ONE HUNDRED THOUSAND POUNDS OF TNT

		Sphere	Hemisphere		Sphere	Hemisphere
Distance		Peak Pressure	Peak Pressure		Positive Impulse	Positive Impulse
(feet)		(psi)	(psi)		(psi-msec)	(psi-msec)
46.7		1605.0	1629.0			
58.5		1538.0	1147.0		1192.0	1170.0
73.1		1258.0	786.5		964.0	1094.0
87.7		972.7	564.8		1000.0	1088.0
102.3		738.6	419.7		1112.0	1146.0
117.0		560.2	320.7		1361.0	1310.0
131.6		448.8	250.8		1690.0	1444.0
146.2		337.4	200.0		1830.0	1544.0
160.8		276.4	162.3		1860.0	1485.0
175.4		215.3	133.7		1813.0	1398.0
204.7		144.9	94.4		1450.0	1234.0
233.9		102.3	69.6		1175.0	1082.0
263.2		75.1	53.2		997.0	971.0
292.4		57.0	41.8		871.0	883.0
350.9		35.6	27.8		713.0	749.0
409.4		24.2	19.9		614.0	649.0
467.8		17.5	15.0		547.0	576.0
526.3		13.3	11.8		496.0	520.0
584.8		10.5	9.61		456.0	474.0
877.2		4.61	4.67		330.0	330.0
1170.0		2.84	2.98		259.0	251.0
1462.0		2.07	2.18		210.0	204.0
1754.0		1.65	1.71		174.0	171.0
2339.0		1.22	1.18		126.0	129.0
2924.0		1.01	0.89		95.9	104.7
4386.0		0.74	0.52		57.3	70.2
5848.0		0.59	0.35		38.6	52.6

FIG. 101 ONE HUNDRED TONS - TWO HUNDRED THOUSAND POUNDS OF TNT

Distance (Feet)		Sphere Peak Pressure (psi)	Hemisphere Peak Pressure (psi)		Sphere Positive Impulse (psi-msec)	Hemisphere Positive Impulse (psi-msec)
80.0		1605.0	1629.0			
100.0		1538.0	1147.0		2039.0	2000.0
125.0		1258.0	786.5		1649.0	1870.0
150.0		972.7	564.8		1710.0	1860.0
175.0		738.6	419.7		1902.0	1960.0
200.0		560.2	320.7		2328.0	2240.0
225.0		448.8	250.8		2890.0	2470.0
250.0		337.4	200.0		3130.0	2640.0
275.0		276.4	162.3		3180.0	2540.0
300.0		215.3	133.7		3100.0	2390.0
350.0		144.9	94.4		2480.0	2110.0
400.0		102.3	69.6		2010.0	1850.0
450.0		75.1	53.2		1705.0	1660.0
500.0		57.0	41.8		1490.0	1510.0
600.0		35.6	27.8		1220.0	1280.0
700.0		24.2	19.9		1050.0	1110.0
800.0		17.5	15.0		936.0	985.0
900		13.3	11.8		848.0	890.0
1000.0		10.5	9.61		779.0	810.0
1500.0		4.61	4.67		565.0	565.0
2000.0		2.84	2.98		443.0	430.0
2500.0		2.07	2.18		359.0	348.0
3000.0		1.65	1.71		298.0	293.0
4000.0		1.22	1.18		216.0	221.0
5000.0		1.01	0.89		164.0	179.0
7500.0		0.74	0.52		98.0	120.0
10000.0		0.59	0.35		66.0	90.0

FIG. 10j FIVE HUNDRED TONS - ONE MILLION POUNDS OF TNT

CHAPTER 11

CYLINDRICAL EXPLOSIONS

Figures 11a-11d give the ratio of the peak overpressure obtained from cylinders (for several length-to-diameter ratios) to that obtained from spheres as a function of the scaled distance, λ, from the charge center. Information is presented both for charges detonated in free air and on the surface.

Present data indicate that over the range of scaled distances presented herein, that Hopkinson or cube-root scaling applies to the cylindrical data. Very close to cylindrical charges cube-root scaling is known not to apply, with a transition region of some sort spanning the gap between the two regions.

All measurements were made at 90° to the longitudinal axis of the cylinder.

Problem Example 1

What pressure would you experience 35 feet from a 6/1 cylinder weighing 125 pounds detonated in free air?

Solution

(a) From Equation 4 of Chapter 1, $\lambda = R/W^{1/3} = 35/(125)^{1/3}$
$= 7\ \text{ft/lb}^{1/3}$

(b) At this scaled distance read the ratio
$P_{cyl}/P_{sph} = 1.40$ for free air from either Figure 11a or 11b.

(c) Go to Figure 3a, at a scaled distance of 7, read the pressure from a sphere: $P_{sph} = 13.9$ psi

(d) $P_{cyl} = 1.4 \times P_{sph} = 1.4 \times 13.9 = 19.5$ psi

Problem Example 2

What pressure would you experience 30 feet from a 3/1 cylinder weighing 216 pounds detonated on the ground?

Solution

(a) From Equation 4 of Chapter 1, $\lambda = R/W^{1/3} = 30/(216)^{1/3}$
$= 5.0\ \text{ft/lb}^{1/3}$

(b) At this scaled distance read the ratio $P_{cyl}/P_{sph} = 1.62$ for a surface burst from either Figure 11c or 11d.

(c) Go to Figure 10c (tangent spheres detonated on the surface); at a $\lambda = 5.0$, read a $P_{sph} = 57$ psi

(d) $P_{cyl} = 1.62 \text{ X } P_{sph} = 1.62 \times 57 = 92$ psi

References:

(1) Wisotski, J. and Snyer, W. H., "Characteristics of Blast Waves Obtained from Cylindrical High Explosive Charges", DRI No. 2286, Denver Research Institute, Nov 1965

(2) Reisler, Ralph, "Air Blast Parameters from Pentolite Cylinders Detonated on the Ground in Various Orientations, BRL report in preparation

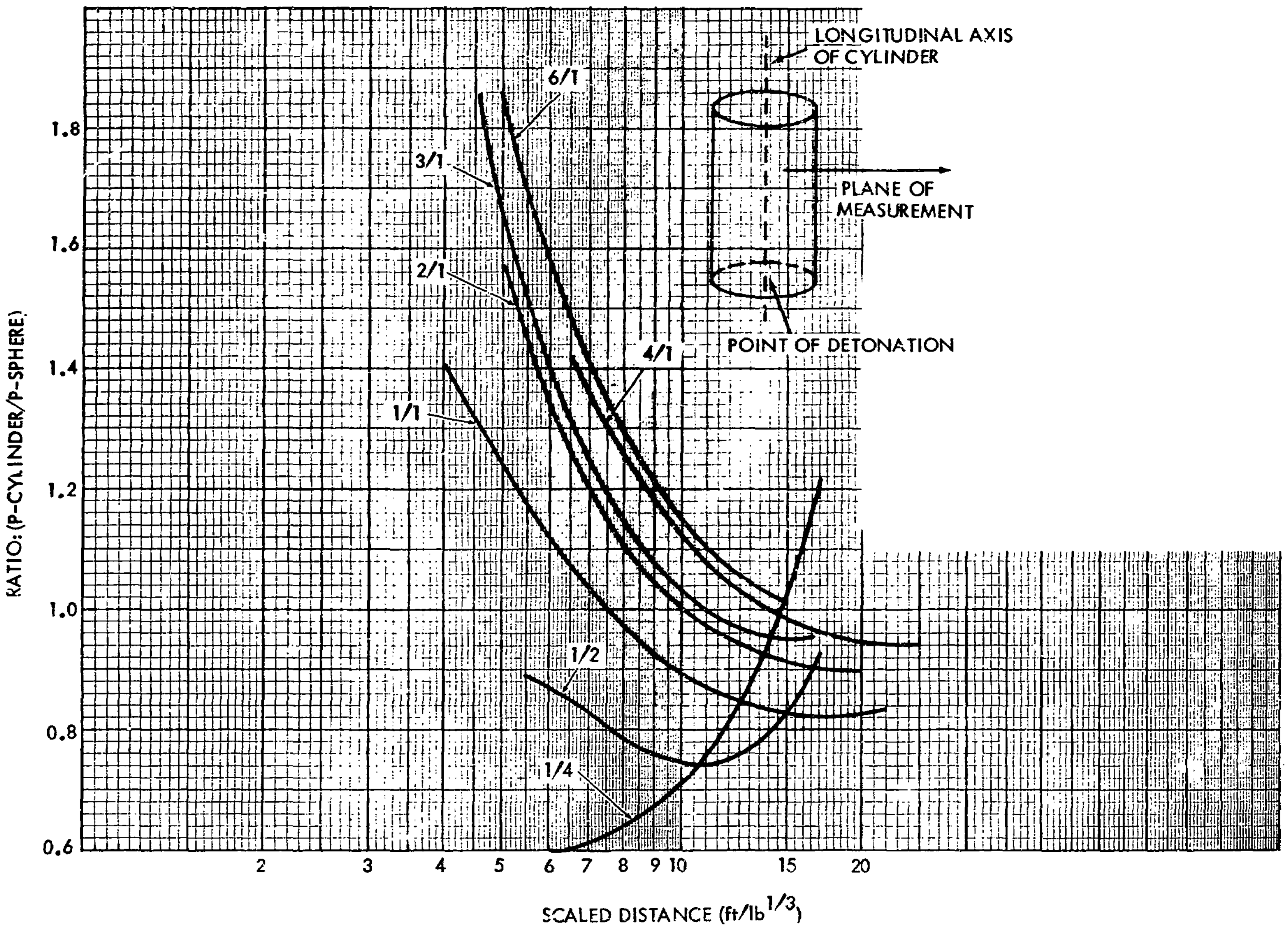


FIG. 11a RATIO OF FREE AIR PEAK OVERPRESSURE (P-CYLINDER/P-SPHERE) VS DISTANCE FOR CYLINDERS WITH DIFFERING ASPECT RATIOS (ℓ/d)

Scaled Distance ($ft/lb^{1/3}$)	Aspect Ratio (ℓ/d)							
	1/4	1/2	1/1	2/1	3/1	4/1	6/1	8/1
4	0.57		1.41					
4.5	0.58		1.32		1.86			
5	0.58		1.24	1.58	1.66		1.84	1.77
5.5	0.59	0.89	1.17	1.44	1.51		1.70	1.63
6	0.60	0.87	1.12	1.34	1.40		1.57	1.53
6.5	0.60	0.85	1.07	1.26	1.31	1.42	1.48	1.45
7	0.61	0.83	1.04	1.20	1.25	1.35	1.41	1.39
7.5	0.63	0.81	1.00	1.15	1.19	1.30	1.34	1.33
8	0.64	0.79	0.97	1.11	1.15	1.26	1.30	1.29
8.5	0.66	0.77	0.95	1.07	1.11	1.22	1.25	1.25
9	0.68	0.76	0.93	1.05	1.08	1.18	1.21	1.22
9.5	0.69	0.75	0.91	1.02	1.06	1.15	1.18	1.19
10	0.71	0.74	0.90	1.00	1.04	1.13	1.15	1.16
10.5	0.73	0.74	0.88	0.99	1.02	1.10	1.13	1.13
11	0.76	0.74	0.87	0.97	1.00	1.08	1.10	1.11
11.5	0.79	0.74	0.86	0.96	0.99	1.06	1.09	1.08
12	0.81	0.75	0.86	0.95	0.98	1.04	1.07	1.06
12.5	0.85	0.76	0.85	0.94	0.97	1.03	1.06	1.04
13	0.88	0.77	0.84	0.94	0.96	1.02	1.05	1.01
13.5	0.91	0.78	0.84	0.93	0.96	1.01	1.04	0.99
14	0.95	0.79	0.83	0.92	0.95	1.0	1.03	0.98
14.5	0.99	0.81	0.83	0.92	0.95	0.99	1.02	0.97
15	1.03	0.83	0.83	0.92	0.95	0.98	1.02	0.96
15.5	1.07	0.85	0.83	0.91	0.95	0.97	1.01	0.95
16	1.12	0.87	0.82	0.91	0.95	0.97		0.94
16.5	1.16	0.90	0.82	0.90	0.95	0.96		0.94
17	1.22	0.93	0.82	0.90	0.96	0.96		0.93
17.5			0.82	0.90	0.96	0.96		0.93
18			0.82	0.90	0.97	0.96		0.92
18.5			0.82	0.90		0.95		0.92
19			0.82	0.90		0.95		0.92
19.5			0.82	0.90		0.95		0.92
20			0.83	0.90		0.95		0.91
20.5			0.83	0.90		0.94		0.91
21			0.84	0.90		0.94		
21.5				0.90		0.94		
22				0.90		0.94		
22.5				0.90		0.94		

FIG. 11b RATIO $P_{CYLINDER}/P_{SPHERE}$ (FREE AIR)

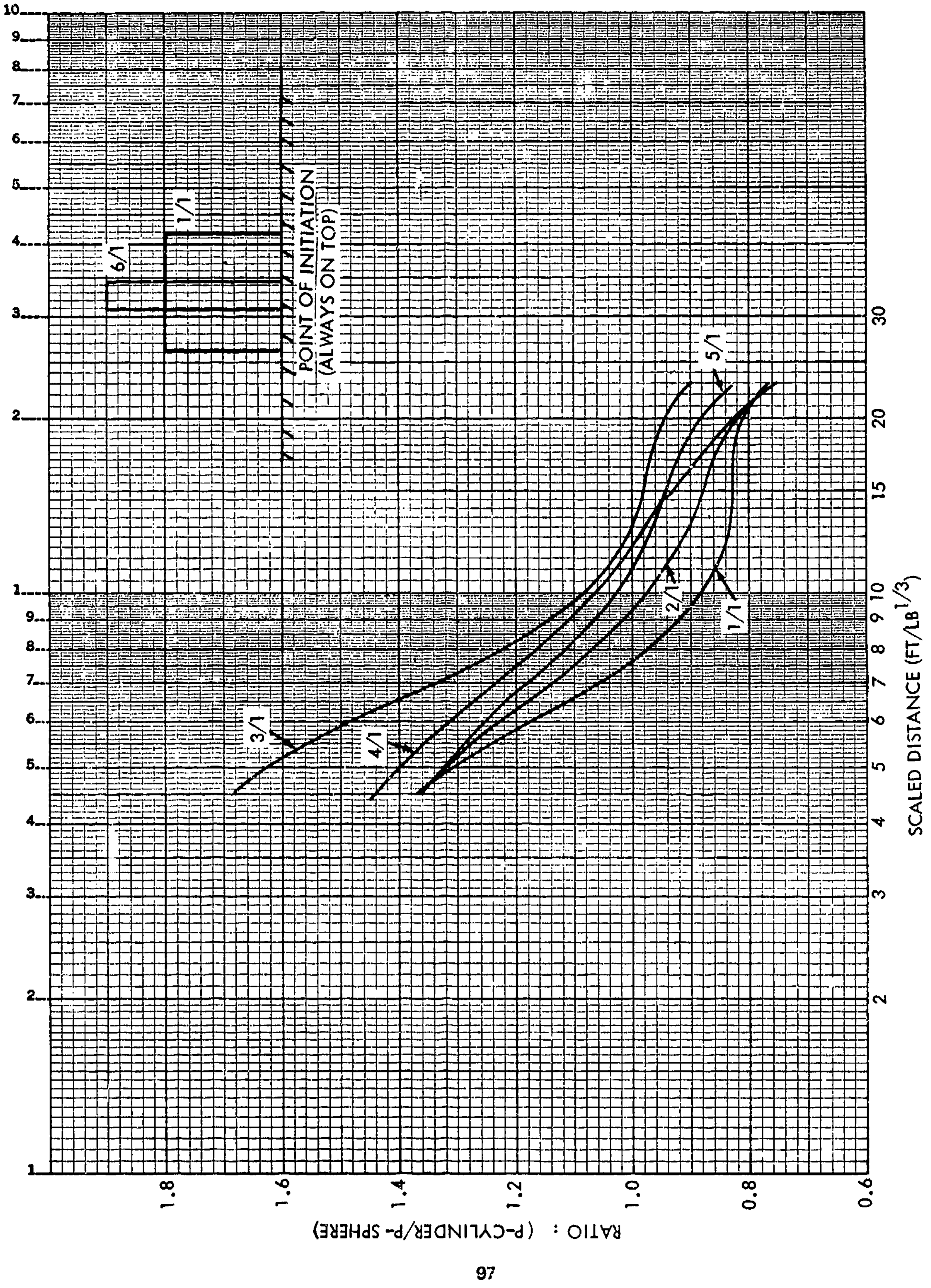


FIG. 11c RATIO OF PEAK OVERPRESSURE (P-CYLINDER/P-SPHERE) VS DISTANCE FOR SURFACE BURST CYLINDERS

Scaled Distance (ft/lb$^{1/3}$)	Aspect Ratio (ℓ/d)				
	1/1	2/1	3/1	4/1	5/1
4.5	1.37	1.36	1.68	1.44	1.36
5.0	1.31	1.32	1.62	1.40	1.32
5.5	1.24	1.28	1.56	1.36	1.29
6.0	1.18	1.23	1.48	1.31	1.25
6.5	1.11	1.18	1.40	1.27	1.21
7.0	1.06	1.14	1.33	1.23	1.18
7.5	1.01	1.10	1.27	1.20	1.14
8.0	0.98	1.07	1.22	1.16	1.12
8.5	0.95	1.04	1.18	1.14	1.09
9.0	0.92	1.02	1.14	1.11	1.07
9.5	0.90	1.00	1.11	1.09	1.05
10.0	0.88	0.98	1.08	1.07	1.03
10.5	0.87	0.96	1.06	1.05	1.02
11.0	0.86	0.95	1.04	1.03	1.00
11.5	0.85	0.93	1.03	1.02	0.99
12.0	0.84	0.92	1.02	1.00	0.98
12.5	0.84	0.91	1.01	0.99	0.98
13.0	0.84	0.90	1.00	0.98	0.97
13.5	0.83	0.90	0.99	0.97	0.96
14.0	0.83	0.89	0.99	0.96	0.96
14.5	0.83	0.89	0.98	0.95	0.95
15.0	0.83	0.88	0.98	0.93	0.94
15.5	0.83	0.87	0.98	0.92	0.94
16.0	0.83	0.87	0.98	0.91	0.93
16.5	0.83	0.87	0.97	0.90	0.93
17.0	0.83	0.86	0.97	0.89	0.92
17.5	0.83	0.85	0.96	0.88	0.92
18.0	0.83	0.85	0.96	0.87	0.91
18.5	0.82	0.84	0.96	0.86	0.90
19.0	0.82	0.84	0.95	0.85	0.90
19.5	0.82	0.83	0.95	0.84	0.89
20.0	0.81	0.82	0.94	0.83	0.88
20.5	0.81	0.81	0.94	0.82	0.87
21.0	0.80	0.81	0.93	0.80	0.87
21.5	0.79	0.80	0.93	0.79	0.86
22.0	0.79	0.79	0.92	0.78	0.85
22.5	0.78	0.78	0.91	0.77	0.84
23.0	0.77	0.77	0.90	0.75	0.83

FIG. 11d RATIO $P_{CYLINDER}/P_{SPHERE}$ (SURFACE BURST)

CHAPTER 12

BLAST CHARACTERISTICS AT THE SHOCK FRONT

The curves in this chapter give the blast characteristics at the shock front--shock velocity, particle velocity, density ratio, dynamic pressure, and reflected pressure as calculated from the Rankine-Hugoniot relations given below:

C	sound velocity at temperature t, °C
U	shock velocity (ft/sec)
u	particle velocity (ft/sec)
C_o	ambient speed of sound (ahead of shock front) (ft/sec) at 0°C--1087 ft/sec
ρ	density of air behind shock front
ρ_o	ambient density of air ahead of shock front
ρ/ρ_o	density ratio across the shock front
q	dynamic pressure (pounds/in^2)
P	peak overpressure at the shock front (pounds/in^2)
P_o	ambient pressure ahead of the shock front, 14.7 psi
P_r	instantaneous reflected overpressure at normal incidence (pounds/in^2)
γ	ratio of the specific heats of the medium (Note: a variable γ was used in these calculations--i.e., a γ for real air which varied with overpressure and density ratio). For almost all calculations below about 1000 psi, an average γ of 1.4 can be used.

$$U = C_o \left(1 + \frac{\gamma+1}{2\gamma} \cdot \frac{P}{P_o}\right)^{1/2} \qquad (1)$$

$$u = \frac{C_o P}{P_o} \left(1 + \frac{\gamma+1}{2\gamma} \cdot \frac{P}{P_o}\right)^{-1/2} \qquad (2)$$

$$\frac{\rho}{\rho_o} = \frac{2\gamma P_o + (\gamma+1)P}{2\gamma P_o + (\gamma-1)P} \qquad (3)$$

$$q = \frac{P^2}{2\gamma P_o + (\gamma-1)P} \qquad (4)$$

$$P_r = 2P + (\gamma+1)q \qquad (5)$$

$$C = C_o \sqrt{1 + \frac{t}{273.16}} \qquad (6)$$

Problem Example 1

What are the shockwave parameters at the shockfront of an 80 psi blast wave propagating into air at 0°C?

Solution

(a) From Figure 12b, for P = 80 psi

Shock velocity = 2603.3 ft/sec

Particle velocity = 1793.9 ft/sec

Density ratio = 3.216

Dynamic pressure = 87.99 psi

Reflected pressure = 370.87 psi

Problem Example 2

For a shockwave traveling 1,400 ft/sec, what is its dynamic pressure?

Solution

(a) From Figure 12a, at U = 1,400 ft/sec, the overpressure is 12 psi, and the dynamic pressure is 3.0 psi

(b) A more accurate answer can be obtained by interpolation in Figure 12b.

(c) From Figure 12b:

$\Delta x = x - 2.21$

Shock Velocity	Dynamic Pressure
1371.1	2.21
1400.0	x
1493.1	4.77

$$\Delta x = \frac{(1400-1371.1)(4.77-2.21)}{(1493.1-1371.1)}$$

$$\Delta x = \frac{(28.9)(2.56)}{122}$$

$$\Delta x = .61$$

$$x = \Delta x + 2.21$$

$$x = 2.82 \text{ psi}$$

(d) A still more accurate answer can be obtained by using equations (1) and (4). By solving equation (1) for P and inserting the result into equation (4), a result of $q = 2.79$ psi is obtained.

Reference:

"The Effects of Nuclear Weapons," S. Glasstone, editor, U. S. Atomic Energy Commission, April 1962

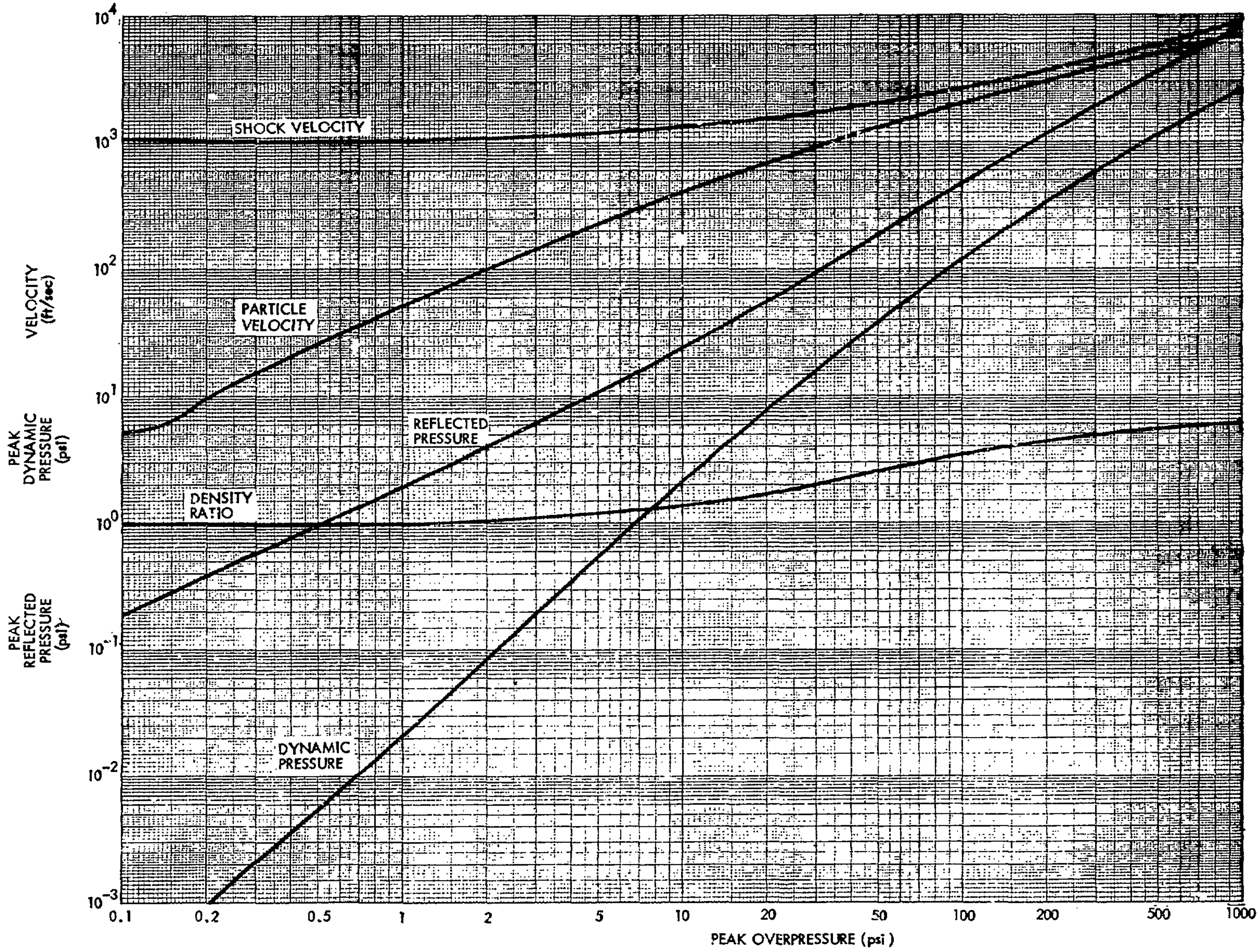


FIG. 12a IDEAL BLAST CHARACTERISTICS AT THE SHOCK FRONT

OVER PRESSURE (PSI)	SHOCK VELOCITY (FT/SEC)	PARTICLE VELOCITY (FT/SEC)	DENSITY RATIO	DYNAMIC PRESSURE (PSI)	REFLECTED PRESSURE (PSI)
.1	1090.2	5.33	1.005	2.42 E-4	.20
.15	1091.8	7.99	1.007	5.45 E-4	.30
.2	1093.4	10.63	1.010	9.69 E-4	.40
.25	1095.0	13.27	1.012	1.51 E-3	.50
.3	1096.6	15.90	1.015	2.18 E-3	.61
.4	1099.8	21.14	1.020	3.87 E-3	.81
.5	1102.9	26.35	1.024	6.04 E-3	1.01
.6	1106.1	31.53	1.029	8.69 E-3	1.22
.7	1109.2	36.68	1.034	1.18 E-2	1.43
.8	1112.4	41.81	1.039	1.54 E-2	1.64
.9	1115.5	46.90	1.044	1.95 E-2	1.85
1.0	1118.7	51.97	1.049	2.40 E-2	2.06
1.5	1134.2	76.89	1.073	5.38 E-2	3.13
2.0	1149.4	101.16	1.097	9.52 E-2	4.23
2.5	1164.5	124.81	1.120	.15	5.36
3	1179.4	147.89	1.143	.21	6.51
4	1208.7	192.42	1.189	.37	8.90
5	1237.2	235.00	1.234	.58	11.39
6	1265.1	275.79	1.279	.83	13.98
7	1292.4	314.98	1.322	1.11	16.68
8	1319.2	352.70	1.365	1.44	19.46
9	1345.4	389.08	1.407	1.81	22.34
10	1371.1	424.23	1.448	2.21	25.31
15	1493.1	584.53	1.643	4.77	41.45
20	1605.8	724.85	1.823	8.14	59.53
25	1711.2	850.51	1.988	12.22	79.33
30	1810.4	964.91	2.141	16.94	100.66
40	1994.2	1168.56	2.415	28.04	147.26
50	2162.5	1347.69	2.654	40.98	198.29
60	2318.7	1509.05	2.864	55.45	252.95
70	2465.1	1656.84	3.050	71.18	310.63
80	2603.3	1793.88	3.216	87.99	370.87
90	2734.5	1922.17	3.366	105.73	433.28
100	2859.8	2043.16	3.502	124.25	497.58
150	3418.7	2569.93	4.028	225.85	840.13

FIG. 12b IDEAL BLAST CHARACTERISTICS AT THE SHOCK FRONT

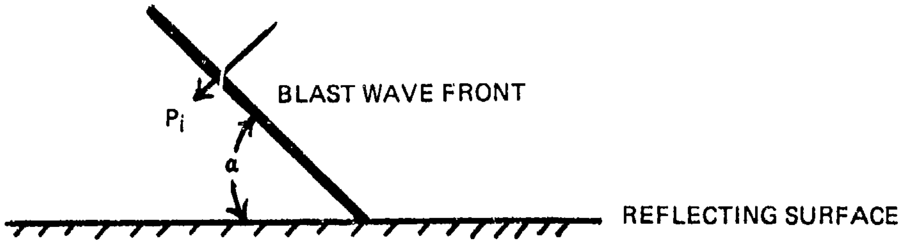
OVER PRESSURE (PSI)	SHOCK VELOCITY (FT/SEC)	PARTICLE VELOCITY (FT/SEC)	DENSITY RATIO	DYNAMIC PRESSURE (PSI)	REFLECTED PRESSURE (PSI)
200	3899.2	3011.65	4.393	337.76	1206.64
250	4327.6	3400.30	4.667	456.58	1588.85
300	4717.9	3751.93	4.884	580.59	1982.63
400	5416.0	4375.76	5.206	838.93	2793.09
500	6036.1	4928.68	5.451	1110.07	3630.77
600	6600.1	5432.38	5.652	1392.74	4492.45
700	7121.6	5899.50	5.827	1686.52	5376.91
800	7609.2	6338.10	5.986	1991.31	6283.75
900	8069.0	6753.66	6.135	2307.1	7212.82
1000	8505.6	7150.08	6.275	2633.88	8164.05

FIG. 12b IDEAL BLAST CHARACTERISTICS AT THE SHOCK FRONT (Continued)

CHAPTER 13

REFLECTED OVERPRESSURE RATIO VS ANGLE OF INCIDENCE FOR VARIOUS INCIDENT OVERPRESSURES

This chapter gives the magnitude of the reflected overpressure versus the angle of incidence of the incident shockwave as a function of the incident overpressure.



$P_o \equiv$ ambient pressure ahead of shock front
$P_i \equiv$ initial incident peak overpressure
$P_r \equiv$ reflected blast wave overpressure
} should be in the same pressure units

$\alpha \equiv$ angle between the blast wave front and the reflecting surface (degrees)

Problem Example 1

A shockwave of 29.4 psi initial peak overpressure strikes a reflecting surface at 35° where the ambient pressure is 14.7 psi. Find the reflected shockwave overpressure.

Solution

(a) $P_i/P_o = \frac{29.4}{14.7} = 2$

(b) From either Figure 13a or 13b, for $P_i/P_o = 2$ at 35°, $P_r/P_i = 3.13$. Thus $P_r = 3.13 \times P_i = 3.13 \times 29.4$

(c) $P_r = 92.0$ psi

Problem Example 2

A 2.2 psi shockwave strikes a reflecting surface at an altitude of 30 Kft at an angle of 60°. Find the reflected pressure.

Solution

(a) From Figure 9 b, at 30,000 ft, the ambient pressure is 4.374 psi

(b) $\frac{P_i}{P_o} = 2.2/4.374 = .50$

(c) From either Figure 13a or 13b, at an angle of 60°, where $P_i/P_o = .5$, $P_r/P_i = 2.11$

(d) $P_r = 2.11 \times P_i = 2.11 \times 2.2$

$P_r = 4.64$ psi

Reference:

Porzel, F. B., "Height of Burst for Atomic Bombs: Part II, Theory of Surface Effects," Los Alamos Scientific Laboratory, Report 1664, May 1954, Unclassified

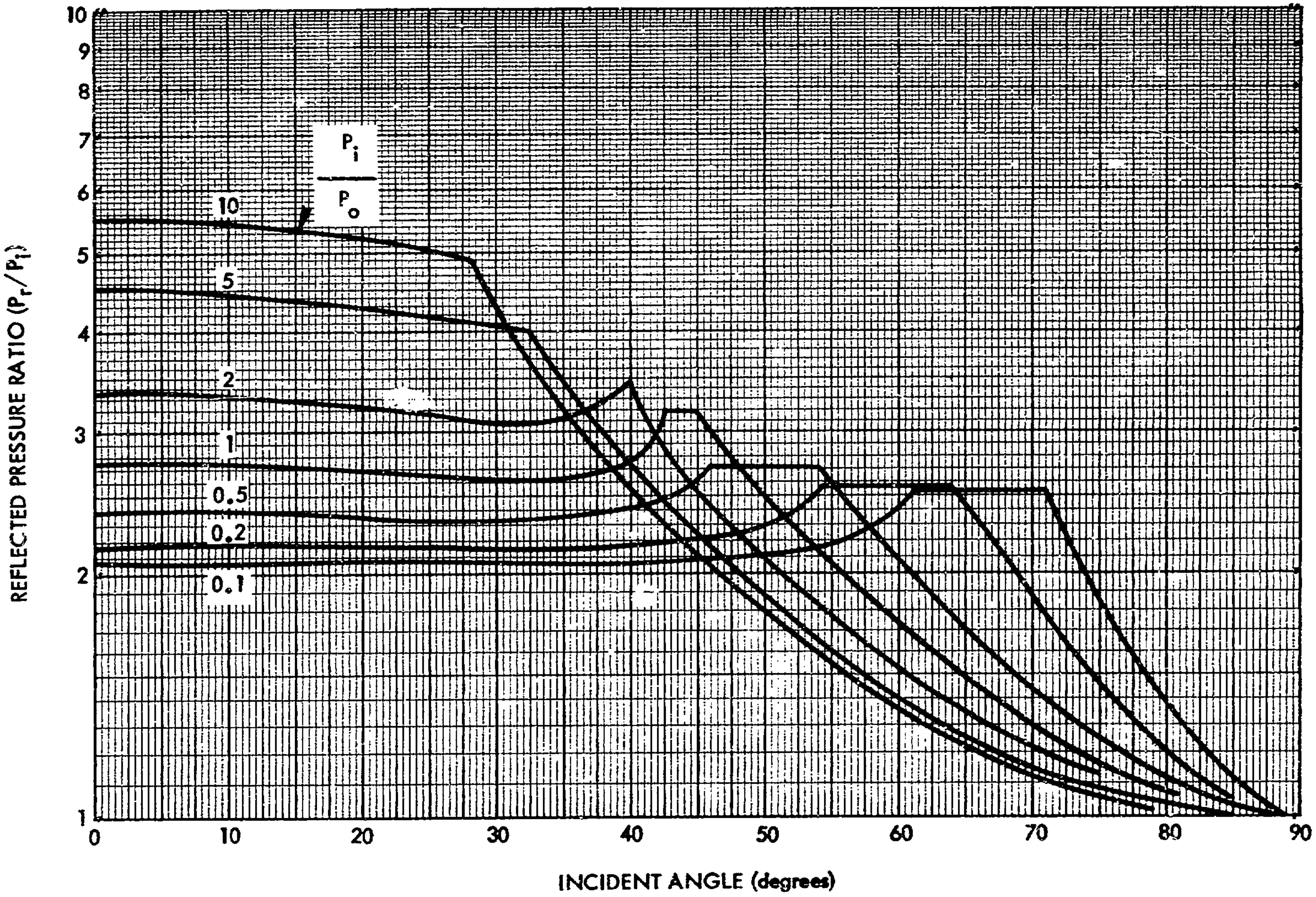


FIG. 13a REFLECTED OVERPRESSURE RATIO VS ANGLE OF INCIDENCE FOR VARIOUS INCIDENT OVERPRESSURE RATIOS

INCIDENT OVERPRESSURE RATIO / ANGLE (degrees)	P_i/P_o										
	0.05	0.10	0.20	0.30	0.50	1.00	2.00	3.00	5.00	10.0	20.0
0	2.04	2.08	2.17	2.25	2.40	2.75	3.33	3.80	4.50	5.53	6.44
5	2.04	2.08	2.17	2.25	2.40	2.75	3.33	3.79	4.48	5.51	6.41
10	2.04	2.08	2.16	2.24	2.39	2.73	3.30	3.76	4.44	5.44	6.33
15	2.04	2.08	2.16	2.24	2.38	2.71	3.26	3.70	4.36	5.32	6.18
20	2.04	2.08	2.15	2.23	2.37	2.69	3.22	3.63	4.26	5.18	5.99
25	2.04	2.08	2.15	2.22	2.36	2.67	3.17	3.56	4.15	5.01	5.77
30	2.04	2.08	2.15	2.22	2.35	2.65	3.13	3.50	4.04	4.35	4.17
35	2.04	2.08	2.15	2.23	2.36	2.66	3.13	3.49	3.51	3.28	3.16
40	2.04	2.09	2.17	2.25	2.41	2.79	3.51	2.97	2.75	2.59	2.50
45	2.05	2.10	2.21	2.32	2.60	3.17	2.58	2.39	2.23	2.12	2.06
50	2.06	2.13	2.30	2.59	2.72	2.53	2.11	1.98	1.87	1.79	1.75
55	2.09	2.21	2.57	2.88	2.63	2.06	1.78	1.68	1.60	1.55	1.52
60	2.14	2.42	2.57	2.63	2.11	1.72	1.53	1.46	1.41	1.37	1.35
65	2.28	2.54	2.49	2.06	1.72	1.47	1.34	1.30	1.27	1.24	1.23
70	2.61	2.54	1.91	1.65	1.44	1.29	1.21	1.18	1.16	1.15	1.14
75	2.61	1.91	1.49	1.35	1.24	1.16	1.11	1.10	1.09	1.08	1.08
80	1.77	1.39	1.21	1.15	1.10	1.07	1.05	1.04	1.04	1.03	1.03
85	1.19	1.10	1.05	1.04	1.03	1.02	1.01	1.01	1.01	1.01	1.01
90	1	1	1	1	1	1	1	1	1	1	1

P_o = local atmospheric pressure

P_i = incident overpressure

P_R = reflected overpressure

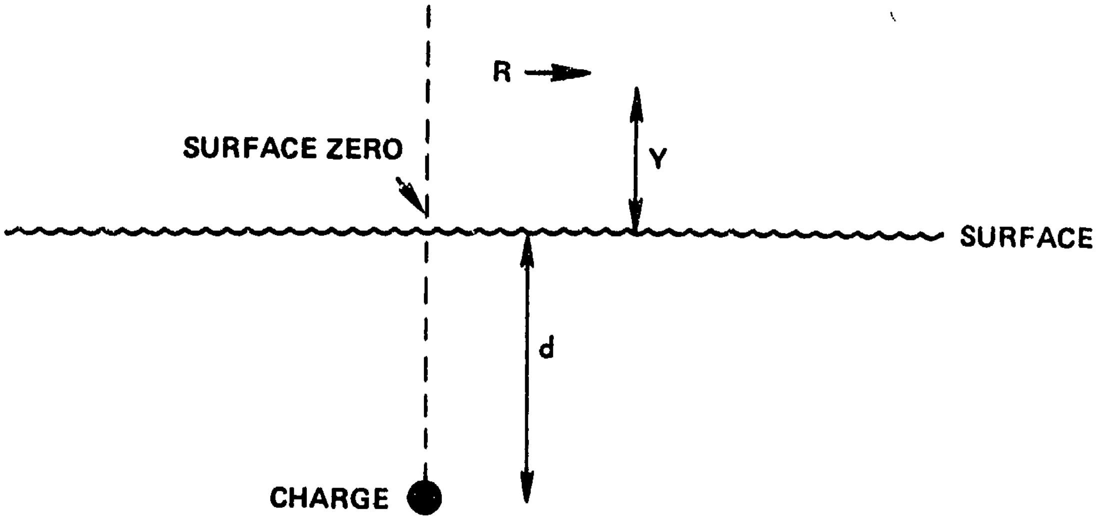
FIG. 13b

REFLECTED OVERPRESSURE RATIO AS A FUNCTION OF ANGLE OF INCIDENCE FOR VARIOUS INCIDENT OVERPRESSURE RATIOS

CHAPTER 14

AIRBLAST FROM UNDERWATER EXPLOSIONS

The geometry for the data in this chapter is shown below:



Figures 14a through 14f present the blast pressure information as fixed functions of λ_Y, with values of λ_Y varying between 0.25 and 40.

λ_d scaled charge depth (ft/lb$^{1/3}$), $d/W^{1/3}$

λ_X scaled horizontal distance (ft/lb$^{1/3}$), $R/W^{1/3}$

λ_Y scaled vertical distance (ft/lb$^{1/3}$), $Y/W^{1/3}$

Because of the scatter in the experimental pressure data used to construct these curves, and the uncertainties involved in making the necessary extrapolations, the curves in this chapter are considered accurate only to within ± 30%.

Problem Example

What is the overpressure at a position 10 feet above the surface, 60 feet from the surface zero ($Y = 10$, $R = 60$) produced by 1,000 pounds of TNT detonated 25 feet below the surface.

Solution

(a) $W = 1{,}000$ pounds

$W^{1/3} = 10$ pounds$^{1/3}$

(b) $\lambda_X = R/W^{1/3} = 60/10 = 6$ ft/(lb TNT)$^{1/3}$

(c) $\lambda_Y = Y/W^{1/3} = 10/10 = 1$ ft/(lb TNT)$^{1/3}$

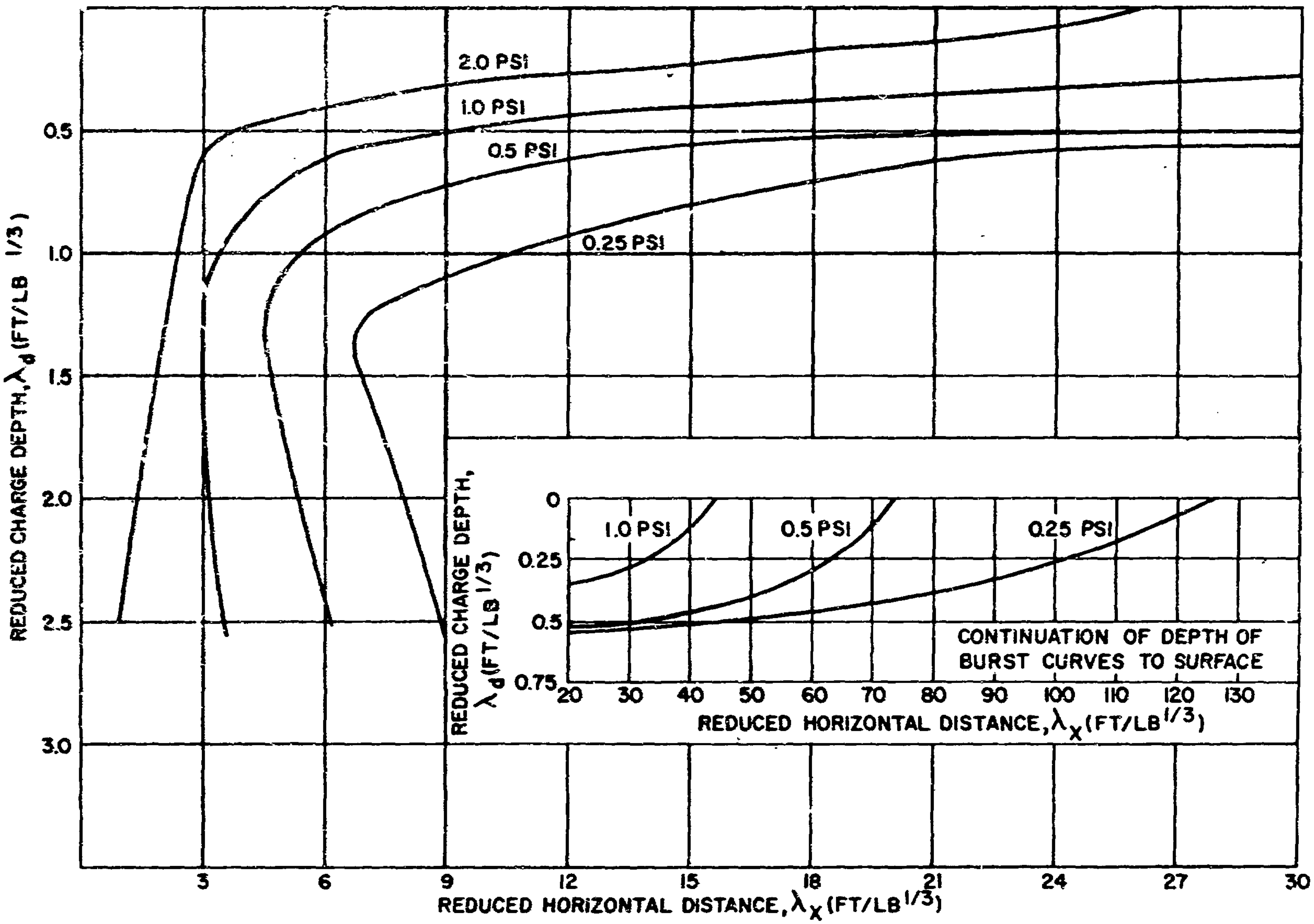
(d) $\lambda_d = d/w^{1/3} = 25/10 = 2.5$ ft/(lb TNT)$^{1/3}$

(e) For $\lambda_Y = 1$, go to Figure 14b. At $\lambda_X = 6$, $\lambda_d = 2.5$, read an overpressure of 0.5 psi

(f) P = 0.5 psi ± 0.15 psi

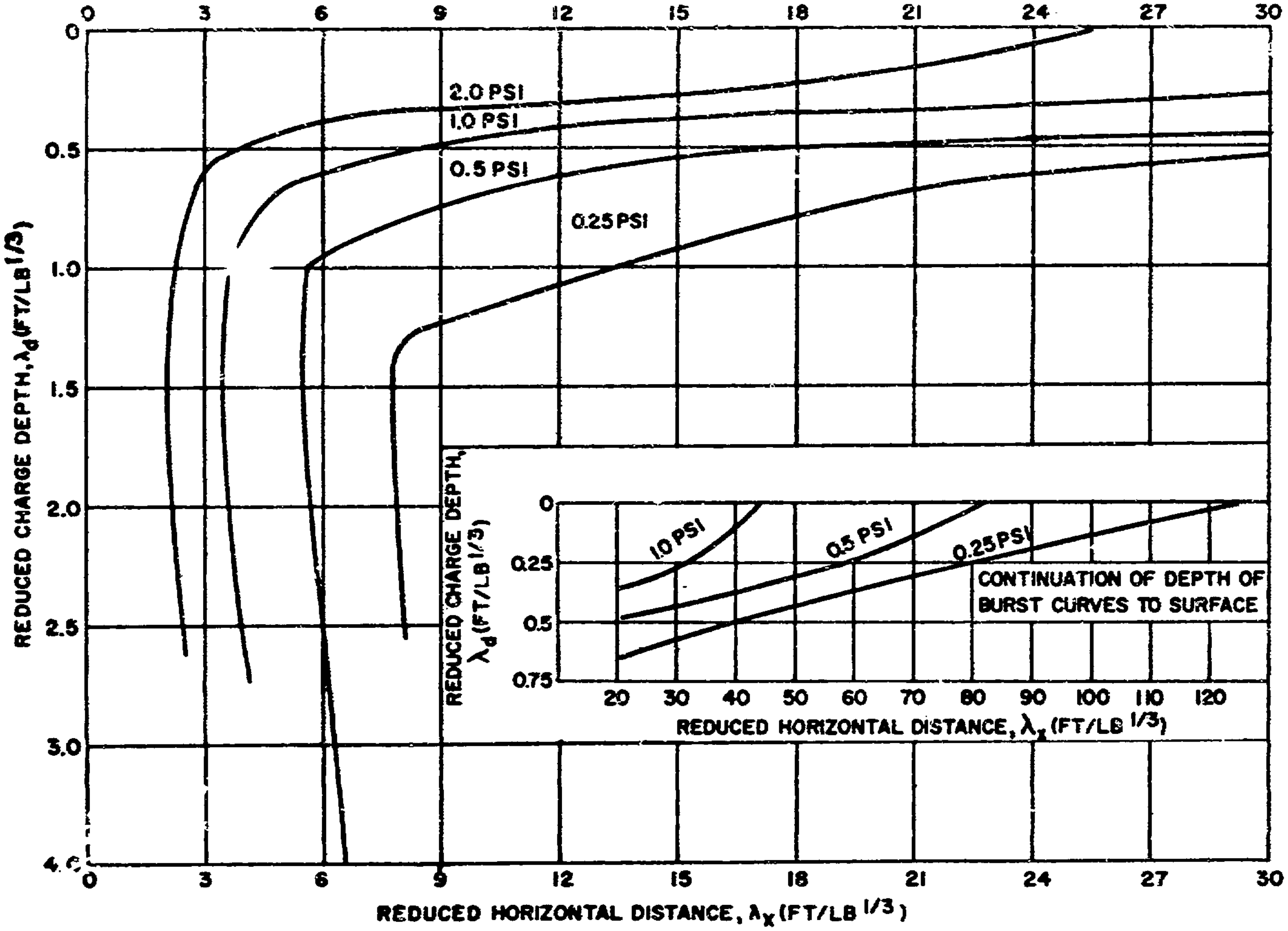
Reference:

Pittman, J. F., "Characteristics of the Air Blast Field Above Shallow Underwater Explosions (U)," NAVORD Report 6106, 5 Dec 1958, Unclassified



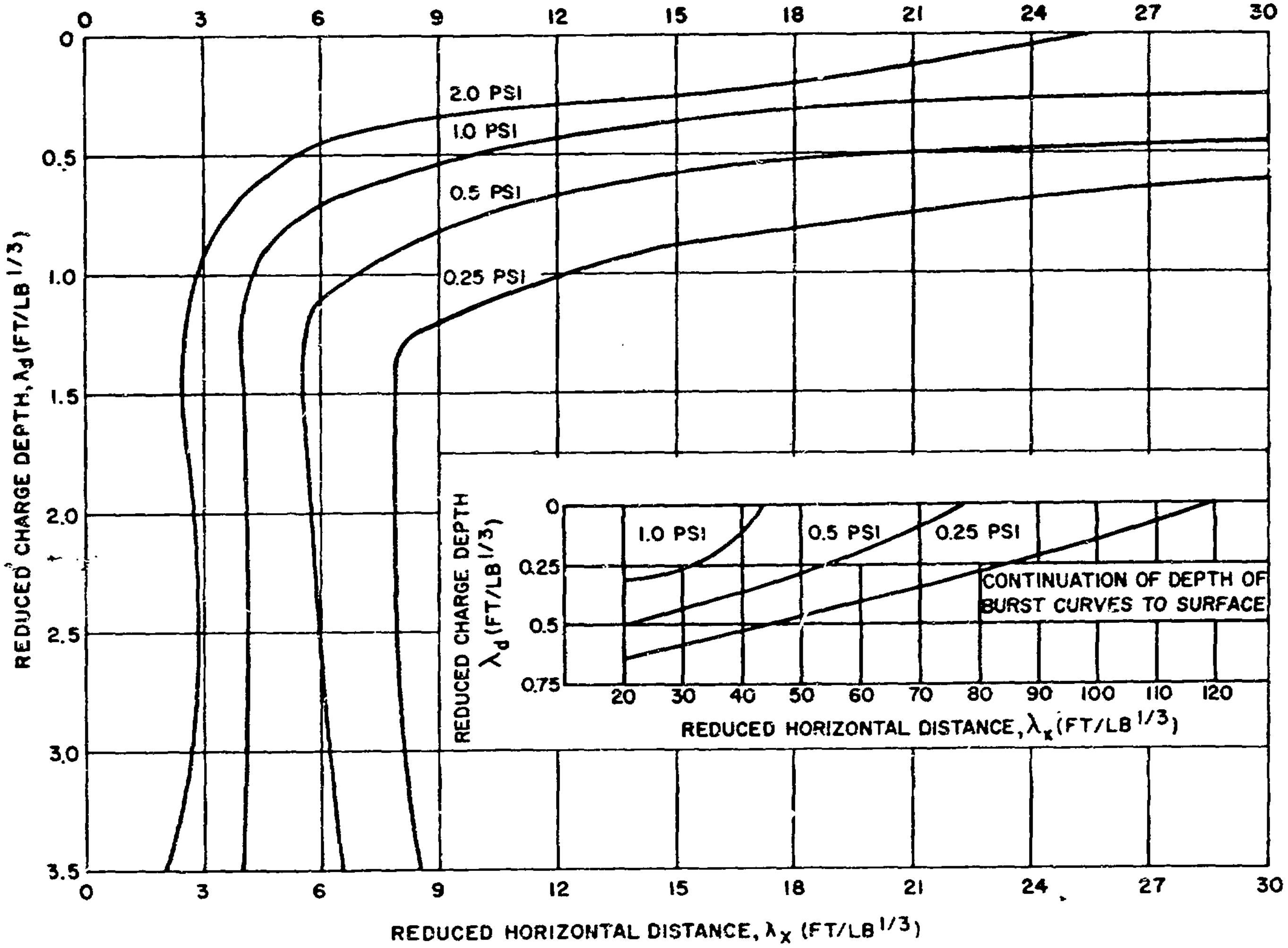
CONSTANT AIR BLAST PRESSURES ALONG A LINE PARALLEL TO THE WATER SURFACE FROM TNT SPHERES FIRED UNDERWATER, λ_y FIXED AT 0.25

F.G. 14a AIRBLAST FROM UNDERWATER EXPLOSIONS



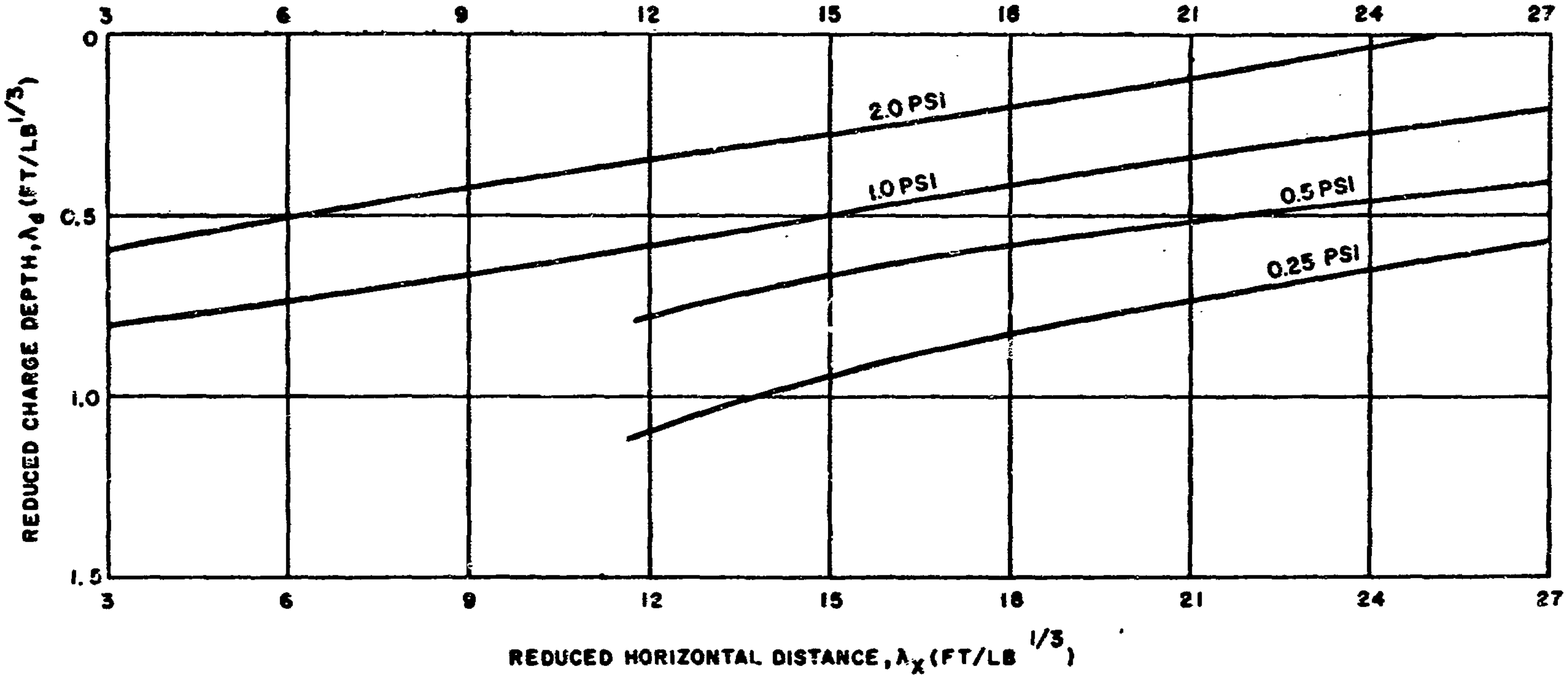
CONSTANT AIR BLAST PRESSURES ALONG A LINE PARALLEL TO THE WATER SURFACE FROM TNT SPHERES FIRED UNDERWATER, λ_y FIXED AT 1

FIG. 14b AIRBLAST FROM UNDERWATER EXPLOSIONS



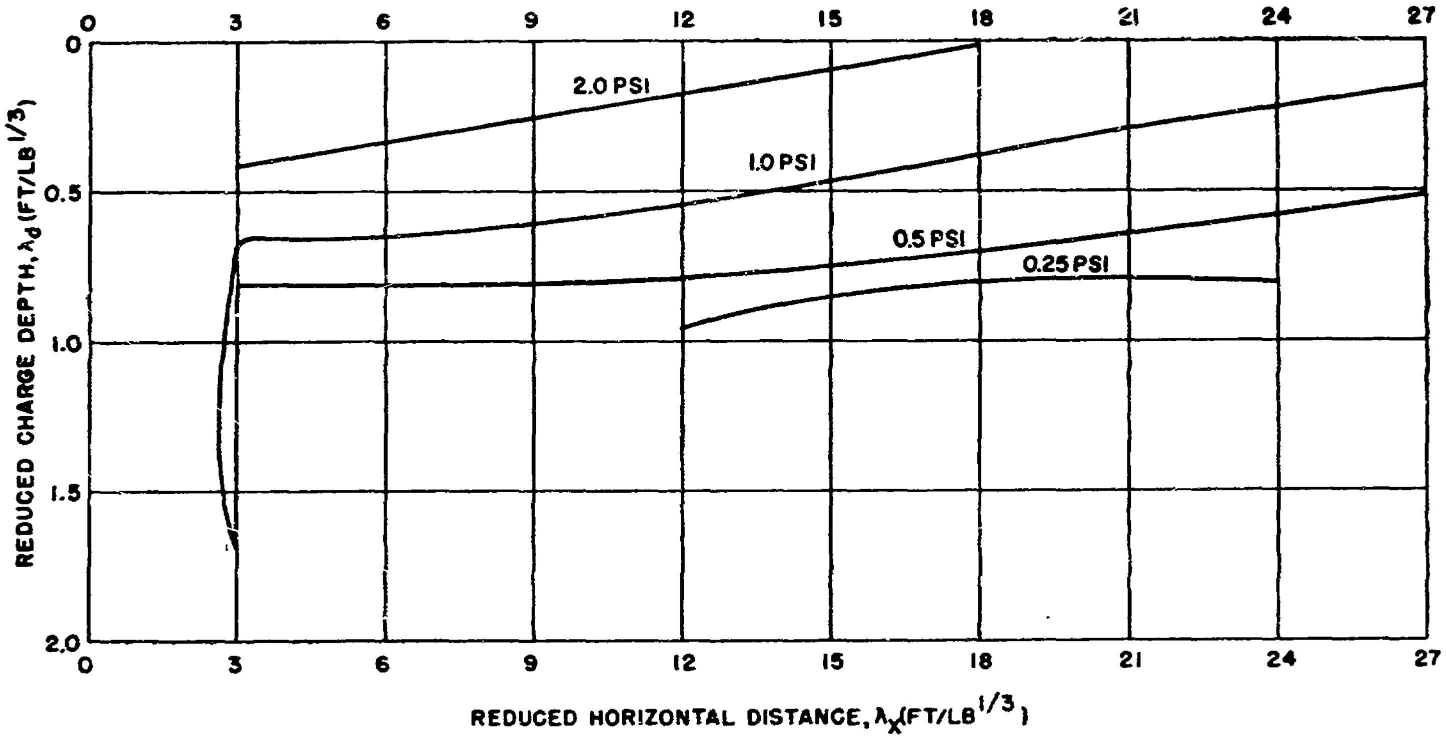
CONSTANT AIR BLAST PRESSURES ALONG A LINE PARALLEL TO THE WATER SURFACE FROM TNT SPHERES FIRED UNDERWATER, λ_y FIXED AT 3

FIG. 14c AIRBLAST FROM UNDERWATER EXPLOSIONS



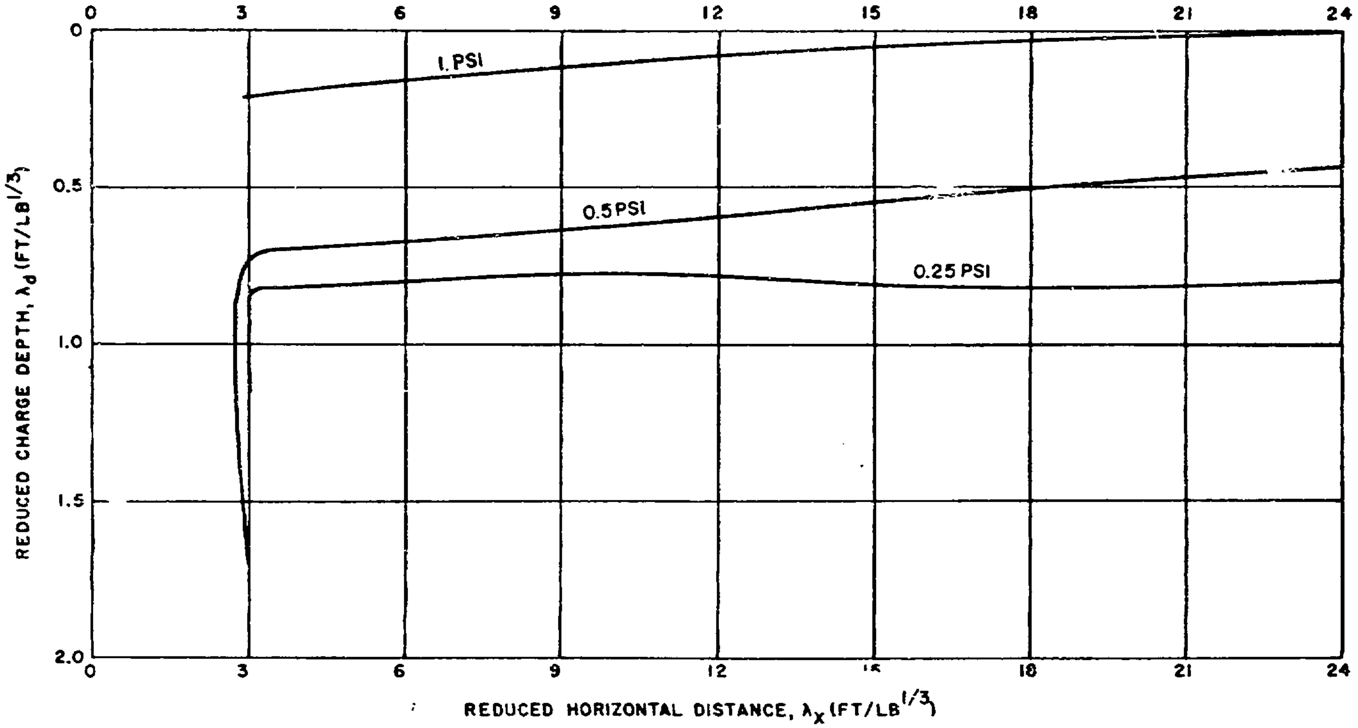
CONSTANT AIR BLAST PRESSURES ALONG A LINE PARALLEL TO THE WATER SURFACE FROM TNT SPHERES FIRED UNDERWATER, λ_y FIXED AT 10

FIG. 14d AIRBLAST FROM UNDERWATER EXPLOSIONS



CONSTANT AIR BLAST PRESSURES ALONG A LINE PARALLEL TO THE WATER SURFACE FROM TNT SPHERES FIRED UNDERWATER, λ_y FIXED AT 20

FIG. 14e AIRBLAST FROM UNDERWATER EXPLOSIONS



CONSTANT AIR BLAST PRESSURES ALONG A LINE PARALLEL TO THE WATER SURFACE FROM TNT SPHERES FIRED UNDERWATER, λ_y FIXED AT 40

FIG. 14f AIRBLAST FROM UNDERWATER EXPLOSIONS

CHAPTER 15

AIRBLAST FROM UNDERGROUND EXPLOSIONS

This chapter gives the peak overpressure from underground explosions as a function of adjusted ground range, $\bar{X}$. The adjusted ground range is a function of ground range, yield, specific gravity of the soil, and the depth of burst.

$\bar{X}$	Adjusted scaled ground range, (ft/lb TNT)$^{1/3}$ $= \lambda_X e^{\rho' \lambda_D}$
D	Depth of explosion in feet
R	Ground range in feet
W	Weight of TNT in pounds
ρ	Specific gravity of soil (see page 128 for representative values)
λ_X	$R/W^{1/3}$
λ_D	$D/W^{1/3}$

This technique is applicable for $\lambda_D \leq 2$ ft/(lb TNT)$^{1/3}$

Problem Example

What is peak airblast overpressure that can be expected at a ground range of 50 feet if 1,000 pounds of TNT are exploded in alluvium 5 feet below the surface?

Solution

(a) $\lambda_D = D/W^{1/3} = 5 \text{ ft}/(1{,}000 \text{ lb})^{1/3}$

$\lambda_D = 0.5 \text{ ft/lb}^{1/3}$

(b) ρ'(for alluvium) = 1.58 (from page 128)

$\rho' \lambda_D = (1.58)\ (0.5) = 0.79 \text{ ft/lb}^{1/3}$

(e) $e^{\rho'\lambda_D} = e^{0.79} = 2.20$

(d) $\lambda_X = R/W^{1/3} = 50 \text{ ft}/(1{,}000 \text{ lb})^{1/3}$

$\lambda_X = 5 \text{ ft/lb}^{1/3}$

(e) $\bar{X} = \lambda_X e^{\rho'\lambda_D} = (5)\ (2.22)$

$\bar{X} = 11.0 \text{ ft/lb}^{1/3}$

(f) From Figure 15, at $\bar{X} = 11.0$, read P = 6 psi

Reference:

"Predictions of Airblast from Underground Bursts," Chemical Rocket/Propellant Hazards, Vol 1, General Safety Engineering Design, Criteria, CPIA Publication 194, Oct 1971

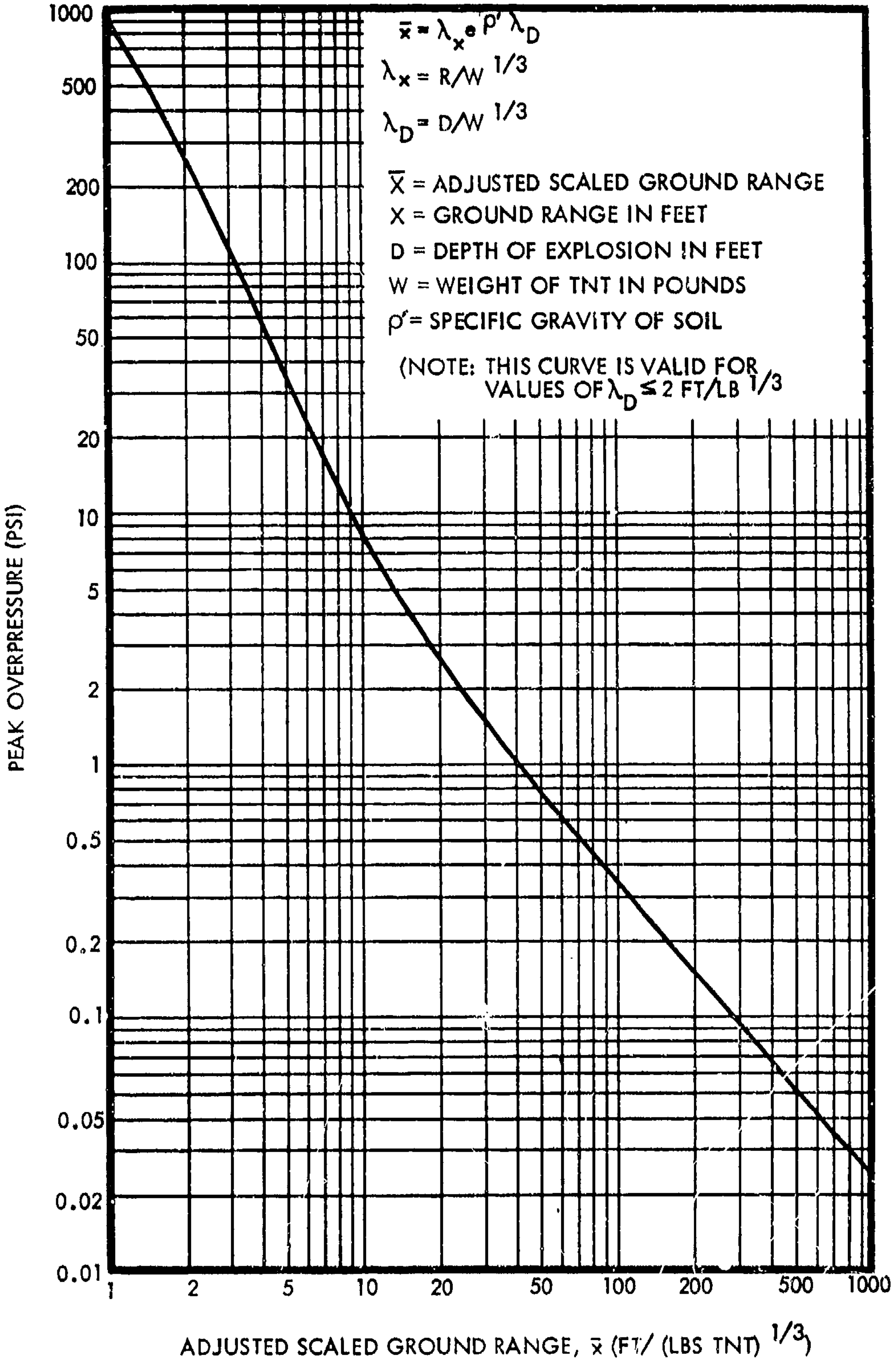


FIG. 15 PEAK OVERPRESSURE FROM UNDERGROUND BURSTS

CHAPTER 16

STATIC PRESSURE FROM EXPLOSIONS IN CONFINED SPACES

For a high explosive detonated in a closed air space, the pressure develops subsequent to shock wave propagation and slowly decays with time as a function of heat conduction variables of the container.

W	charge weight, pounds
V	chamber volume, i.e., volume of confined air, ft^3
ΔP_o	static pressure above ambient in psi

Figures 16a and 16b give the peak static pressure for a given W/V (charge weight/volume) ratio for TNT up to a W/V of 2×10^{-2} lb/ft^3. For the W/V range covered by this chapter, to determine the pressure produced by another explosive, multiply the TNT pressure by the factor given for the explosive in the table on Figure 16a. The range of values of W/V given in Figure 16a are extended to include incomplete combustion and tabulated in Figure 16b.

Problem Example 1

What static pressure will be generated by 10 pounds of TNT in an enclosed volume of 2,000 ft^3?

Solution

(a) $W/V = 10/2000 = 5 \times 10^{-3}$ lb/ft^3

(b) Enter the graph at this W/V value

(c) Read the pressure of 58 psi

Problem Example 2

What static pressure will be generated by 10 pounds of PETN in an enclosed volume of 2,000 ft^3?

Solution

(a) $W/V = 10/2000 = 5 \times 10^{-3}$ lb/ft^3

(b) Enter the graph at this W/V value

(c) Read the pressure of 58.0 psi

(d) Multiply this pressure by the factor for PETN given in Figure 16a:0.57; $58.0 \times 0.57 = 33.0$ psi

Problem Example 3

What static pressure will be generated by 100 pounds of H-6 in an enclosed volume of 1,000 ft^3?

Solution

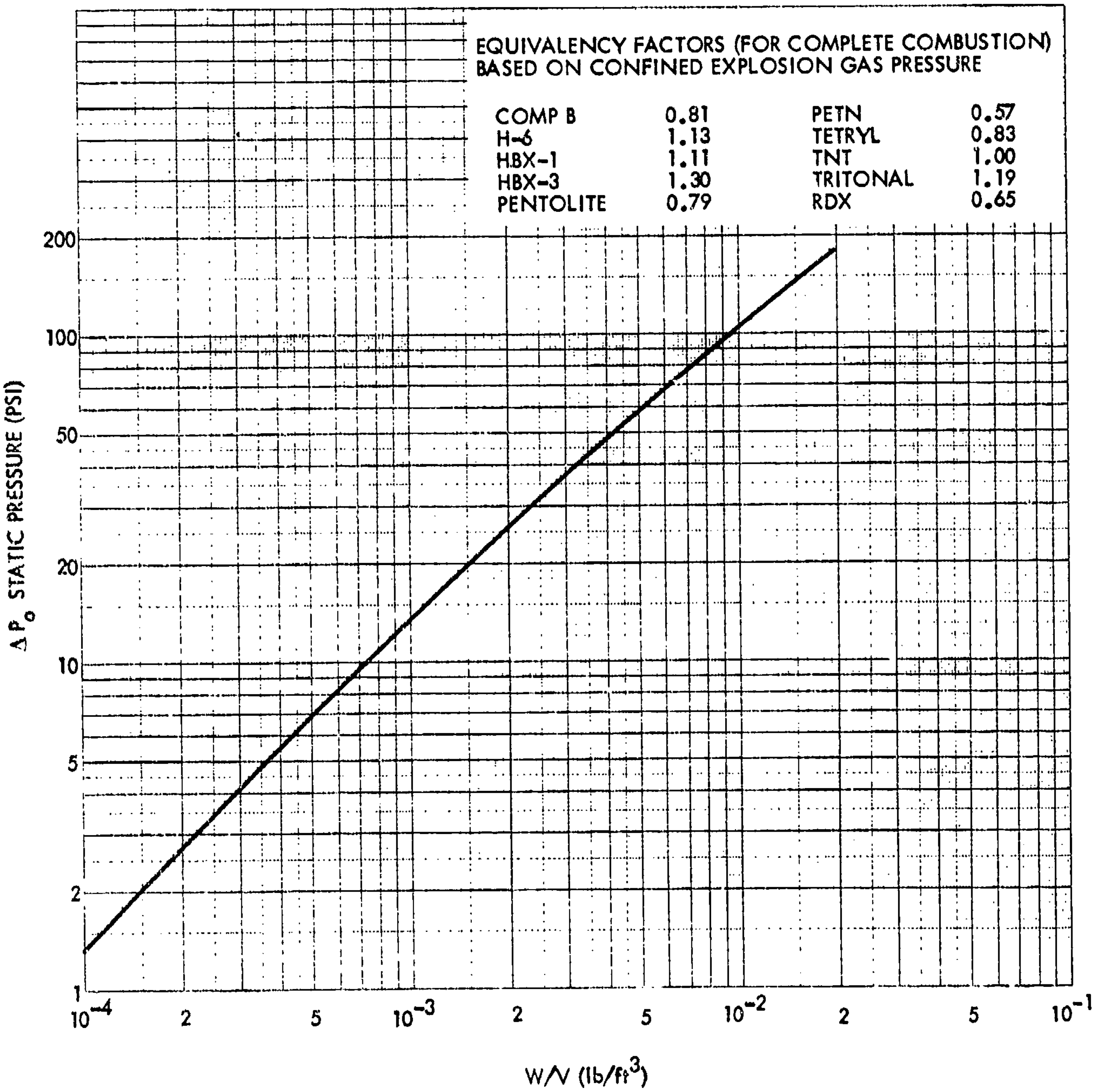
(a) $W/V = 100/1000 = 10^{-1}$ lb/ft^3

(b) Note that this value $(10^{-1}) > 2 \times 10^{-2}$ so that the graph cannot be used

(c) Enter Figure 16b at $W/V = 10^{-1}$ and go across to the column labeled H-6. Read the pressure of 426.7 psi

Reference:

Proctor, J. F., "Internal Blast Damage Mechanisms Computer Program," NOLTR 72-231, 31 Aug 1972



EQUIVALENCY FACTORS (FOR COMPLETE COMBUSTION) BASED ON CONFINED EXPLOSION GAS PRESSURE

COMP B	0.81	PETN	0.57
H-6	1.13	TETRYL	0.83
HBX-1	1.11	TNT	1.00
HBX-3	1.30	TRITONAL	1.19
PENTOLITE	0.79	RDX	0.65

FIG. 16a STATIC OVERPRESSURE FROM EXPLOSIONS IN CONFINED SPACES

Fig. 16b Static Overpressure from Explosions in Confined Spaces

STATIC OVERPRESSURE (PSI)

W/V (lbs/ft^3)	TNT	Pentolite	Comp. B	Tritonal	H-6	HBX-1	HBX-3	RDX	PETN	Tetryl
1 x 10^{-4}	1.36	1.05	1.08	1.67	1.57	1.54	1.86	0.85	0.74	1.11
1.5	2.04	1.57	1.62	2.49	2.36	2.31	2.79	1.27	1.10	1.66
2.0	2.71	2.09	2.16	3.32	3.14	3.08	3.71	1.69	1.47	2.21
4.0	5.40	4.17	4.31	6.61	6.25	6.14	7.39	3.38	2.93	4.41
6.0	8.09	6.24	6.45	9.85	9.32	9.16	11.0	5.05	4.39	6.60
8.0	10.7	8.30	8.58	13.0	12.3	12.1	14.4	6.73	5.84	8.78
1 x 10^{-3}	13.3	10.3	10.7	16.1	15.2	15.0	17.8	8.39	7.29	10.9
1.5	19.5	15.2	15.7	23.4	22.2	21.9	25.8	12.5	10.9	16.1
2.0	25.4	20.0	20.6	30.3	28.8	28.4	33.3	16.4	14.3	21.1
4.0	47.0	37.4	38.6	55.3	52.8	52.1	60.4	31.2	27.3	39.4
6.0	66.6	53.4	55.2	77.6	74.3	73.4	84.4	44.8	39.3	56.1
8.0	85.0	68.4	70.7	98.2	94.2	93.2	106.2	57.7	50.6	71.8
1 x 10^{-2}	102.4	82.7	85.6	117.4	112.8	111.7	126.4	70.1	61.4	86.8
1.5	142.7	116.1	120.5	160.8	155.1	154.0	171.2	99.5	87.0	122.0
2.0	179.9	147.1	153.1	199.4	193.1	192.2	210.2	127.3	111.0	154.7
4.0	242.3	257.9	267.6	272.4	283.8	277.7	285.9	229.1	198.4	265.3
6.0	282.9	317.5	324.8	323.0	340.3	334.2	316.2	323.2	278.2	321.7
8.0	323.9	372.3	381.6	364.2	385.0	381.0	341.3	413.3	354.3	377.8
1 x 10^{-1}	367.6	427.0	438.2	402.7	426.7	425.3	384.3	482.9	428.2	433.7
1.5	475.6	563.2	579.0	492.3	524.2	530.4	489.5	649.4	607.8	573.0
2.0	582.6	699.0	717.7	577.4	617.1	631.5	592.8	815.8	770.4	711.9
4.0	1007	1241	1268	903.7	1023	1024	986.2	1482	1390	1261
6.0	1430	1780	1816	1223	1449	1410	1355	2148	2009	1807
8.0	1853	2318	2364	1541	1874	1811	1724	2814	2629	2352
1 x 10^{0}	2275	2857	2911	1859	2299	2210	2093	3481	3248	2898
1.5	3331	4202	4279	2650	3361	3230	3018	5146	4797	4260
2.0	4386	5548	5647	3441	4423	4251	3942	6812	6346	5623

CHAPTER 17

THE EFFECTIVE BARE CHARGE WEIGHT OF A CASED WEAPON

The effective bare charge weight of a steel cased weapon will lie somewhere between the actual explosive weight contained in the bomb (W) and the effective charge weight (W_e).

Recent experiments have indicated that equation (1) below, an expression for W_e, may not be valid in many instances. Currently, this problem is being investigated.

W/W_T = Charge to total weight ratio of a cylindrical section

W = Actual weight of explosive in cylindrical section, lb

M = Metal case weight of cylindrical section, lb

W_T = Total weight of cylindrical section, lb, $W_T = W + M$

W_T must not include the weight of the end pieces; failure to observe this caution can result in determining effective bare charge weights that are to low.

W_e = Effective bare charge weight for peak overpressure, lb

$W_e/1.19$ = Effective bare charge weight for impulse, lb

The nomograph in Figure 17 represents the following semi-empirical equation:

$$W_e = \left[\frac{1+M(1-M')/W}{1+M/W}\right] \text{ X } 1.19\ W \qquad (1)$$

M/W = Metal to charge weight ratio of a cylindrical section of the weapon = $(W_T/W)-1$

M' = M/W for all values of M/W less than one; use M' equal to one for all values of M/W greater than one

Problem Example

What is the effective bare charge weight of a 1000-lb semi-armor piercing bomb (SAP)? Actual weight of explosive in bomb is 320 lb. Charge to total weight of a cylindrical section is 0.38.

Solution 1

(a) Connect 0.38 on W/W_T scale with 320 on W scale in Figure 17 and read answer on W_e scale, 145 lb

Solution 2

(a) $\frac{M}{W} = \frac{W_T}{W} - 1 = \frac{1}{0.38} - 1 = 1.632$

(b) $\frac{M}{W} > 1, \therefore M' = 1$ (from the definition of M' given previously)

(c) $W_e = (1.19)\ (320) \left[\frac{1}{1+1.632}\right] = \frac{(1.19)(320)}{2.632}$

$W_e = 145$ lb

References:

(1) Fisher, E. M., "The Effect of the Steel Case on the Air Blast High Explosives," NAVORD Report 2753, 1953

(2) Filler, W. S., "A New Approach to Airblast from Cased Explosives," NOLTR 70-66, Oct 1970

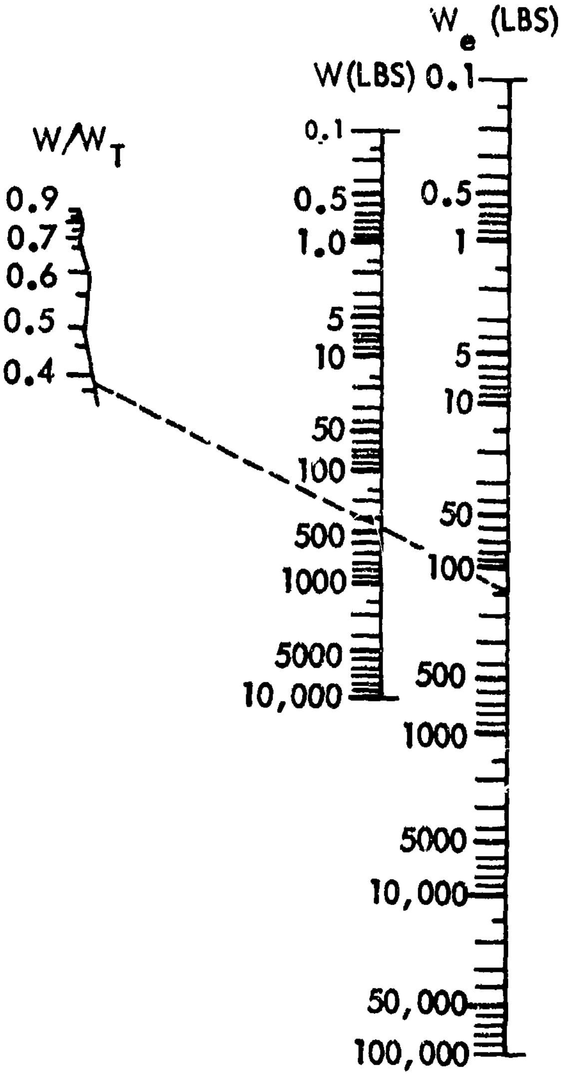


FIG. 17 THE EFFECTIVE BARE CHARGE WEIGHT OF A CASED WEAPON

CHAPTER 18

APPARENT CRATER PARAMETERS VS DEPTH OF BURIAL IN VARIOUS MEDIA

The figures in this Chapter give the apparent crater dimensions produced by the detonation of spherical TNT charges in several media. Note that instead of the usual "cube root" scaling, i.e., $W^{1/3}$, scaling based on $W^{5/16}$ is used for scaling crater dimensions.

Crater parameters are defined in Figure 18a. Because of the inherent problems in determining crater dimensions, the indicated values could be in error by as much as ± 25%.

The five media considered are:

(1) Alluvium
(2) Basalt
(3) Dry Clay Shale
(4) Playa
(5) Sand

Sand is well-known, so it doesn't need definition. As for the other four:

(1) Alluvium is a sedimentary soil, usually composed of sand and clay, which has generally been deposited by flowing water.

(2) Basalt is a dark, heavy igneous rock, comprising most of the lava in the world.

(3) Clay Shale is a rock formed from hardened mud, clay, and silt. Shale is the most abundunt sedimentary rock.

(4) Playa is essentially a sun-baked mixture of clay, silt, and salt. It is typical desert soil formed by the evaporation of water from closed depressions on the desert surface.

Some of the average physical properties of each of these media are presented in the accompanying table.

	Alluvium	Basalt	Clay Shale	Playa	Sand
Specific gravity	1.58	2.58	2.74	2.56	2.65
Dry weight (lb/ft^3)	102	161	104	75	112
Moisture Content (%)	8.1	1.5	23	14	6.6
Youngs Modulus (psi)	1.6×10^5	6.1×10^6	3.5×10^5	3.0×10^4	1.2×10^6
Shear Modulus (psi)	5.9×10^4	2.6×10^6	1.25×10^5	1.5×10^4	4.7×10^5
Cohesion (psi)	11	3000	21	6.6	4

Problem Example

What are the apparent crater dimensions produced by 1000 pounds of TNT detonated 15 feet below the surface in sand?

Solution

(a) $W = 1000$ lb; $W^{5/16} = 8.66\ (lb^{5/16})$

(b) Scaled Depth of Burst $(\lambda_D) = D/W^{5/16} = 15/8.66$
$= 1.73\ ft/lb^{5/16}$

(c) From Figure 18i, for the scaled depth of burst of 1.73 $ft/lb^{5/16}$, by linear interpolation

scaled crater radius, $R_a/W^{5/16} = 2.16\ ft/lb^{5/16}$

scaled crater depth, $D_a/^{5/16} = 1.14\ ft/lb^{5/16}$

scaled crater volume, $V_a^{1/3}/W^{5/16} = 2.32\ ft^{1/3}/lb^{5/16}$

hence, (d)

apparent crater radius, $R_a = 2.16\ \mathrm{ft/lb}^{5/16} \times 8.66\ \mathrm{lb}^{5/16} = 18.7\ \mathrm{ft}$

apparent crater depth, $D_a = 1.14\ \mathrm{ft/lb}^{5/16} \times 8.66\ \mathrm{lb}^{5/16} = 9.9\ \mathrm{ft}$

$$V_a^{1/3} = 2.32\ \mathrm{ft}^{1/3}/\mathrm{lb}^{5/16} \times 8.66\ \mathrm{lb}^{5/16} = 20.1\ \mathrm{ft}^{1/3}$$

apparent crater volume, $V_a = 8100\ \mathrm{ft}^3$

or alternatively, using Figures 18b, c, and d

(c) $R_a/W^{5/16} = 2.16\ \mathrm{ft/lb}^{5/16}$

$D_a/W^{5/16} = 1.14\ \mathrm{ft/lb}^{5/16}$

$V_a^{1/3}/W^{5/16} = 2.32\ \mathrm{ft}^{1/3}/\mathrm{lb}^{5/16}$

(d) $R_a = 2.16 \times 8.66 = 18.7\ \mathrm{ft}$

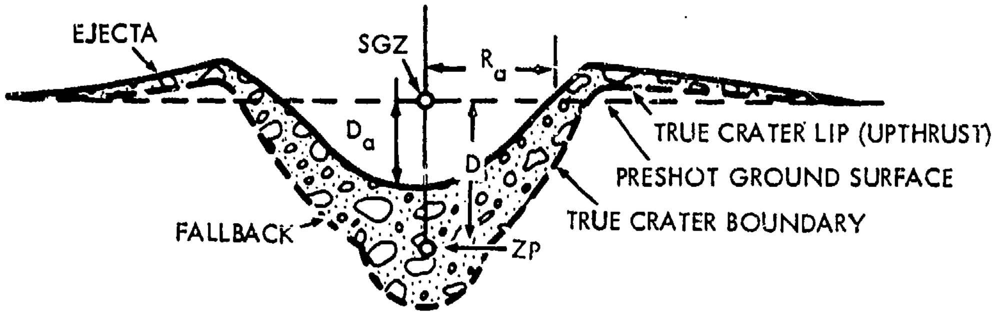
$D_a = 1.14 \times 8.66 = 9.9\ \mathrm{ft}$

$V_a^{1/3} = 2.32 \times 8.66 = 20.1\ \mathrm{ft}^{1/3}$

$V_a = 8100\ \mathrm{ft}^3$

Reference:

Dillon, L. A., "The Influence of Soil and Rock Properties on the Dimensions of Explosion Produced Craters," AFWL-TR-71-144, February 1972



R_a-RADIUS OF APPARENT CRATER MEASURED AT PRESHOT GROUND SURFACE

D_a-MAXIMUM DEPTH OF APPARENT CRATER BELOW PRESHOT GROUND SURFACE

V_a-VOLUME OF APPARENT CRATER BELOW PRESHOT GROUND SURFACE

D-DEPTH OF BURST (DISTANCE TO ZP FROM SGZ)

ZP-ZERO POINT (EFFECTIVE CENTER OF EXPLOSION ENERGY)

SGZ-SURFACE GROUND ZERO (POINT ON SURFACE VERTICALLY ABOVE ZP)

FIG. 18a CRATER PARAMETERS

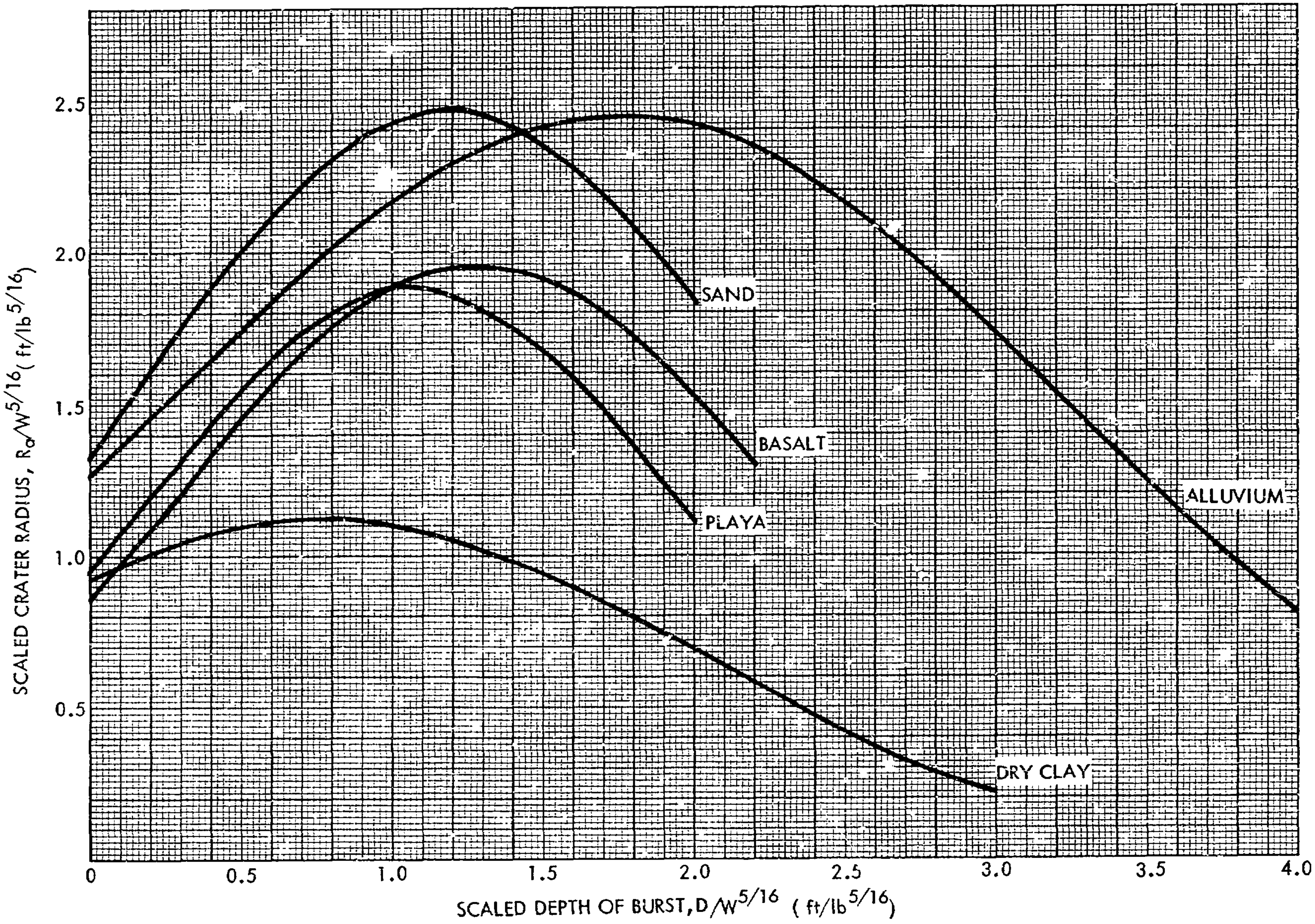


FIG. 18b APPARENT CRATER RADIUS VS DEPTH OF BURIAL IN VARIOUS MEDIA

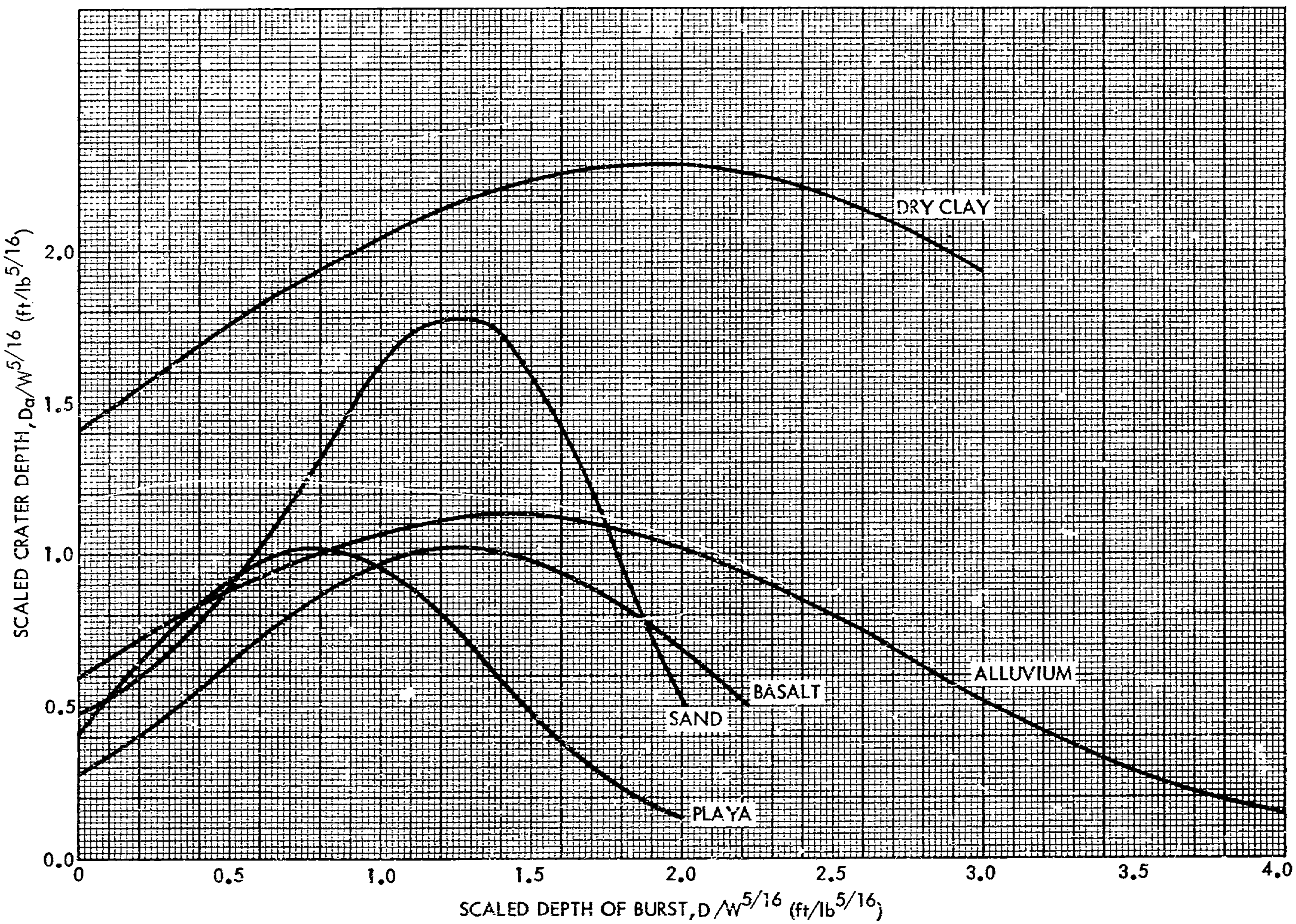


FIG. 18c APPARENT CRATER DEPTH VS DEPTH OF BURIAL IN VARIOUS MEDIA

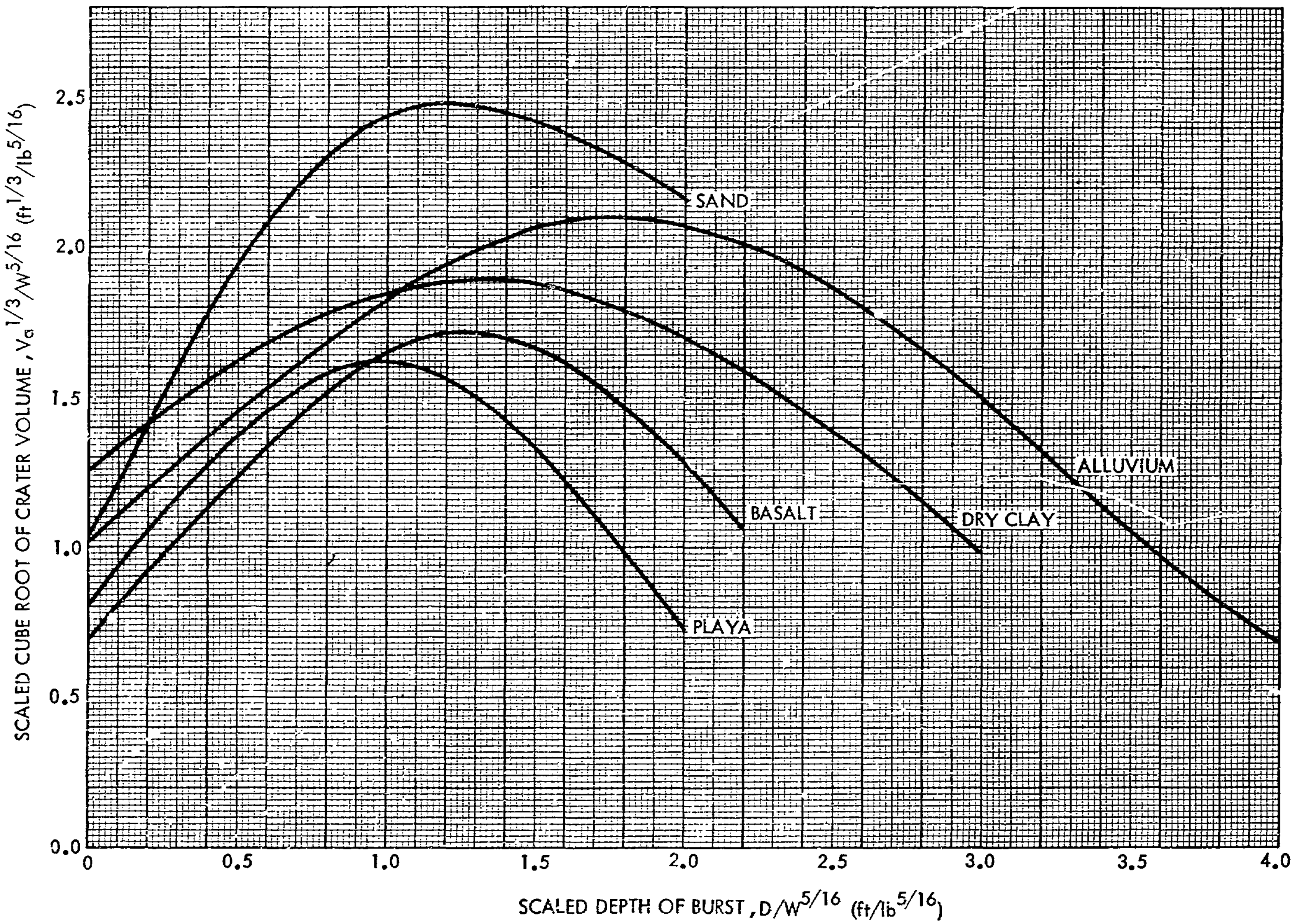


FIG. 18d CUBE ROOT OF APPARENT CRATER VOLUME VS DEPTH OF BURIAL IN VARIOUS MEDIA

λ_D	λ_{R_a}	λ_{D_a}	λ_{V_a}
0	1.26	.60	1.02
.1	1.36	.66	1.11
.2	1.45	.72	1.19
.3	1.55	.78	1.28
.4	1.65	.83	1.36
.5	1.74	.88	1.45
.6	1.84	.92	1.53
.7	1.93	.96	1.61
.8	2.01	1.00	1.69
.9	2.09	1.04	1.76
1.	2.17	1.07	1.83
1.1	2.23	1.09	1.89
1.2	2.29	1.11	1.95
1.3	2.34	1.13	1.99
1.4	2.38	1.13	2.03
1.5	2.41	1.13	2.06
1.6	2.43	1.12	2.08
1.7	2.44	1.10	2.10
1.8	2.44	1.08	2.10
1.9	2.43	1.05	2.09
2.	2.41	1.02	2.07
2.1	2.38	.98	2.04
2.2	2.34	.94	2.01
2.3	2.28	.89	1.97
2.4	2.23	.85	1.92
2.5	2.16	.80	1.86
2.6	2.08	.75	1.80
2.7	2.00	.69	1.72
2.8	1.92	.63	1.65
2.9	1.83	.57	1.57
3.	1.73	.52	1.50
3.1	1.64	.47	1.40
3.2	1.54	.42	1.32
3.3	1.44	.37	1.23
3.4	1.35	.33	1.15
3.5	1.25	.28	1.06
3.6	1.16	.25	.98
3.7	1.06	.22	.90
3.8	.98	.19	.82
3.9	.89	.17	.75
4.	.81	.14	.68

FIG. 18e APPARENT CRATER PARAMETERS VS DEPTH OF BURIAL FOR ALLUVIUM

λ_D = Scaled Depth of Burst, $D/W^{5/16}$ $(ft/lb^{5/16})$

λ_{R_a} = Scaled Radius, $R_a/W^{5/16}$ $(ft/lb^{5/16})$

λ_{D_a} = Scaled Depth, $D_a/W^{5/16}$ $(ft/lb^{5/16})$

λ_{V_a} = Scaled Cube Root of Volume, $V_a^{1/3}/W^{5/16}$ $(ft/lb^{5/16})$

FIG. 18e APPARENT CRATER PARAMETERS VS DEPTH OF BURIAL FOR ALLUVIUM (Continued)

λ_D	λ_{R_a}	λ_{D_a}	λ_{V_a}
0	.86	.28	.69
.1	.97	.34	.80
.2	1.09	.40	.92
.3	1.20	.48	1.03
.4	1.32	.56	1.13
.5	1.44	.64	1.24
.6	1.54	.73	1.33
.7	1.65	.90	1.43
.8	1.74	.86	1.52
.9	1.81	.92	1.59
1.	1.88	.97	1.65
1.1	1.92	1.00	1.69
1.2	1.95	1.02	1.72
1.3	1.95	1.02	1.71
1.4	1.94	1.01	1.69
1.5	1.91	.98	1.66
1.6	1.86	.94	1.61
1.7	1.80	.89	1.54
1.8	1.72	.83	1.46
1.9	1.63	.76	1.37
2.	1.52	.68	1.28
2.1	1.41	.60	1.17
2.2	1.30	.52	1.06

λ_D = Scaled Depth of Burst, $D/W^{5/16}$ (ft/lb$^{5/16}$)

λ_{R_a} = Scaled Radius, $R_a/W^{5/16}$ (ft/lb$^{5/16}$)

λ_{D_a} = Scaled Depth, $D_a/W^{5/16}$ (ft/lb$^{5/16}$)

λ_{V_a} = Scaled Cube Root of Volume, $V_a^{1/3}/W^{5/16}$ (ft/lb$^{5/16}$)

FIG. 18f APPARENT CRATER PARAMETERS VS DEPTH OF BURIAL FOR BASALT

λ_D	λ_{R_a}	λ_{D_a}	λ_{V_a}
0	.93	1.41	1.26
.1	.97	1.48	1.33
.2	1.01	1.55	1.41
.3	1.05	1.62	1.48
.4	1.07	1.69	1.55
.5	1.10	1.76	1.62
.6	1.11	1.82	1.68
.7	1.12	1.88	1.73
.8	1.12	1.94	1.78
.9	1.12	1.99	1.82
1.	1.10	2.04	1.84
1.1	1.08	2.09	1.87
1.2	1.06	2.14	1.88
1.3	1.02	2.18	1.89
1.4	.99	2.20	1.89
1.5	.95	2.23	1.88
1.6	.90	2.26	1.86
1.7	.85	2.28	1.83
1.8	.80	2.28	1.79
1.9	.74	2.28	1.75
2.	.69	2.28	1.70
2.1	.64	2.26	1.65
2.2	.58	2.24	1.58
2.3	.53	2.24	1.52
2.4	.48	2.21	1.45
2.5	.43	2.18	1.38
2.6	.38	2.14	1.31
2.7	.34	2.09	1.24
2.8	.30	2.04	1.15
2.9	.26	1.99	1.06
3.	.23	1.93	.98

λ_D = Scaled Depth of Burst, $D/W^{5/16}$ (ft/lb$^{5/16}$)

λ_{R_a} = Scaled Radius, $R_a/W^{5/16}$ (ft/lb$^{5/16}$)

λ_{D_a} = Scaled Depth, $D_a/W^{5/16}$ (ft/lb$^{5/16}$)

λ_{V_a} = Scaled Cube Root of Volume, $V_a^{1/3}/W^{5/16}$ (ft/lb$^{5/16}$)

FIG. 18g APPARENT CRATER PARAMETERS VS DEPTH OF BURIAL FOR DRY CLAY

λ_D	λ_{R_a}	λ_{D_a}	λ_{V_a}
0	.95	.41	.80
.1	1.08	.53	.93
.2	1.20	.64	1.06
.3	1.32	.74	1.17
.4	1.44	.83	1.28
.5	1.55	.91	1.37
.6	1.65	.98	1.46
.7	1.74	1.01	1.53
.8	1.80	1.02	1.58
.9	1.85	1.00	1.61
1.	1.88	.95	1.62
1.1	1.88	.89	1.60
1.2	1.86	.80	1.56
1.3	1.82	.70	1.50
1.4	1.76	.59	1.42
1.5	1.68	.48	1.33
1.6	1.59	.38	1.22
1.7	1.48	.30	1.10
1.8	1.36	.23	.98
1.9	1.24	.17	.86
2.	1.12	.14	.73

λ_D = Scaled Depth of Burst, $D/W^{5/16}$ (ft/$lb^{5/16}$)

λ_{R_a} = Scaled Radius, $R_a/W^{5/16}$ (ft/$lb^{5/16}$)

λ_{D_a} = Scaled Depth, $D_a/W^{5/16}$ (ft/$lb^{5/16}$)

λ_{V_a} = Scaled Cube Root of Volume, $V_a^{1/3}/W^{5/16}$ (ft/$lb^{5/16}$)

FIG. 18h APPAREENT CRATER PARAMETERS VS DEPTH OF BURIAL FOR PLAYA

λ_D	λ_{R_a}	λ_{D_a}	λ_{V_a}
0	1.33	.48	1.05
.1	1.47	.54	1.22
.2	1.60	.60	1.41
.3	1.74	.68	1.60
.4	1.87	.78	1.78
.5	2.00	.90	1.94
.6	2.11	1.02	2.09
.7	2.21	1.17	2.20
.8	2.30	1.32	2.30
.9	2.37	1.48	2.38
1.	2.42	1.63	2.44
1.1	2.45	1.73	2.47
1.2	2.46	1.77	2.48
1.3	2.44	1.78	2.47
1.4	2.41	1.72	2.45
1.5	2.35	1.58	2.42
1.6	2.28	1.42	2.38
1.7	2.19	1.21	2.33
1.8	2.08	.97	2.28
1.9	1.96	.74	2.22
2.	1.83	.52	2.16

λ_D = Scaled Depth of Burst, $D/W^{5/16}$ (ft/lb$^{5/16}$)

λ_{R_a} = Scaled Radius, $R_a/W^{5/16}$ (ft/lb$^{5/16}$)

λ_{D_a} = Scaled Depth, $D_a/W^{5/16}$ (ft/lb$^{5/16}$)

λ_{V_a} = Scaled Cube Root of Volume, $V_a^{1/3}/W^{5/16}$ft/lb$^{5/16}$)

FIG. 18i APPARENT CRATER PARAMETERS VS DEPTH OF BURIAL FOR SAND

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