SIMPLIFIED KINGERY AIRBLAST CALCULATIONS

presented by

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ABSTRACT

In July 1980, the DDESB Explosive Safety Standard DOD 6055.9-STD became linked with or referenced to the 1966 Kingery Hemispherical TNT Surface Burst airblast compilation. In 1984, a revised Kingery compilation was released. The 1984 Kingery paper presented the compiled airblast parameters in terms of high order polynomials. This paper presents the same results in terms of simplified polynomials with the results accurate to within 1% of the original Kingery values. The paper also describes the background and basis of the Kingery Standard--what it is as well as what it is not. Moreover, it provides guidance on its limitations and applicability.

INTRODUCTION

In the current DOD Explosives Safety Standard[1], the effects expected at a particular scaled distance (range/charge weight$^{1/3}$) are tied to a pressure level. This pressure level is determined from the 1966 Kingery hemispherical TNT compilation.[2] This was not always the case. The first instance in which an effect was tied to a pressure level was in Interim Change 2 to DOD 5154.4S, dated 23 June 1980[3]. Here, pressure levels were tied to scaled distances or K factors through the use of the Kingery hemispherical TNT surface burst data compilation which was released in 1966. Subsequent to the publication of the original compilation, a revised and updated compilation was prepared for inclusion in a revision to the 1969, tri-service manual Structures to Resist the Effects of Accidental Explosions.[4,5] This new compilation[6], also by Kingery and Bulmash was published in 1984.

Since its adoption by the Department of Defense Explosives Safety Board (DDESB), questions have been raised about this compilation. Questions such as What is it? What are its limitations? What should I know about it in order to use it properly? The following sections of this paper will begin to address some of these questions.

KINGERY--1966

The 1966 Kingery compilation is based on the airblast data taken on four large (5-500 ton) TNT events which were conducted in Canada between 1959 and 1964. Airblast data were recorded on these events by representatives from the United States, Canada, and the United Kingdom. Their results were combined to form the data base from which the 1966 compilation was

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produced. The overpressure results for the first three events were reported by Kingery and Pannill in an interim report published in 1964[7].

The following table shows the scope of the data which was used for the 1966 compilation:

CHART 1

EVENT NUMBER	NOMINAL YIELD (tons of TNT)	DATE
1	5	1959
2	20	1960
3	100	1961
4	500	1964

Quoting from the 1966 Kingery report, ...The data from all four tests were first processed to obtain the as read values of peak overpressure, arrival time, positive duration and positive impulse. The cube root scaling and altitude corrections were applied to these values to bring them to standard sea-level conditions and the equivalent of a one-pound charge. The scaled values were then used to determine the curves presented in this report.

This 1966 effort only addressed four airblast parameters--Time of Arrival, Peak Overpressure, Positive Phase Duration, and Positive Phase Impulse. It further limited itself to hemispherical TNT surface bursts. It was strictly curve fits to empirical data. No attempt was made to match the data with a theory or with hydrocode calculations.

A question which should be addressed at this point is How well do the curve fits presented by Kingery in 1966 match the data. This is addressed in the following table. In each case 2/3 of all the data points lie within the error bounds shown below:

CHART 2

PARAMETER*	ERROR (%)**
SCALED TIME OF ARRIVAL	± 1.8
PEAK OVERPRESSURE	± 6.4
SCALED POSITIVE PHASE DURATION	± 9.6
SCALED POSITIVE PHASE IMPULSE	± 6.7

*Scaled to 1-pound at sea level conditions
**2/3 of data fall within this error band

With such a relatively small error band, it is apparent that the curve fits represent the data extremely well.

KINGERY & BULMASH--1984

The hemispherical TNT-portion of the 1984 Kingery and Bulmash effort is, basically, a re-examination of the 1966 data. No additional data were examined or included. Although no new data were included, information on reflected pressure, reflected impulse, and shock front velocity were also presented. The following table presents the sources of all of the information included in this work:

CHART 3

PARAMETER	SOURCE
SCALED TIME OF ARRIVAL	Re-fit original data in BRL Report 1344
PEAK OVERPRESSURE	Re-fit original data in BRL Report 1344
SCALED POSITIVE PHASE DURATION	Re-fit original data in BRL Report 1344
SCALED POSITIVE PHASE IMPULSE	Re-fit original data in BRL Report 1344
REFLECTED PRESSURE	Calculated--note 1
REFLECTED IMPULSE	Calculated--note 2
SHOCK FRONT VELOCITY	Calculated--note 3

Note 1: Calculated using Peak Overpressure and variable specific heat ratio
Note 2: Calculated from Free Air TNT Reflected Impulse data
Note 3: Calculated from Peak Overpressure

LIMITATIONS OF KINGERY COMPILATIONS

It must be remembered that the data set utilized in these two compilations are, by no means, complete. There have been numerous hemispherical TNT surface burst detonations since 1964. None of these data are included.

The data included in these compilations are real-world data taken under real-world conditions. This means that any inherent variations in the performance of the explosive is included in the data. Further, since the data were taken under real-world conditions, the effects of weather (temperature gradients and winds) are included. No attempt was or has been made to quantify these effects.

The data set does not address such airblast parameters as negative phase pressure, negative phase duration, negative phase impulse, and total blast wave duration (positive plus negative phase). It should be noted that if ones interest is in these parameters, then other sources of information are available[8].

As indicated in the sections above, the parameter fits are empirical--no pre-determined or externally imposed forms or coefficients have been applied.

CURRENT WORK

In 1992, at the request of members of the DDESB Secretariat, the author was requested to prepare simplified curve fits for the Kingery & Bulmash hemispherical TNT compilation. At the same time, the author was requested to extend the Kingery and Bulmash incident pressure curve to include lower pressures.

After further discussions with members of the DDESB Secretariat, it was proposed that these simplified and extended curve fits form the basis for computing airblast parameters for the scaled distances referred to in the DOD Explosives Safety Standard[1]. These curve fits would be used as the basis of comparison for computation of effective explosives weight (EEW) for hazard classification[9]. It would not be intended for research purposes or as an absolute comparison for theoretical computations.

The guidelines used in simplifying the curve fits for this proposed standard were quite simple: (1) the equations must be much easier to use than those presented in Kingery and Bulmash and (2) the simplified equations must predict the Kingery and Bulmash results with an average error of less than 1%. The work of Kingery and Pannill[7] would be used to extend the incident pressure curves to lower levels.

Table 1 presents the proposed standard in terms of polynomial curve fits for both Metric and English units. Questions are often raised about the slope of the pressure-distance curve. This information, although not included in the original Kingery & Bulmash work, is easily derived from the curve fit information presented. This slope information is presented in Table 2.

Using the curve fits presented in Tables 1 and 2, summary tables of the various airblast parameters are presented in Tables 3 and 4 for both Metric and English Units. Tables 5 and 6 present the errors which are introduced by using these simplified equations. As can be seen, the average error is significantly less than 1%, assuming the 1984 Kingery curves are the standard.

These new curve fits can now be used to generate pressure levels for many of the scaled distances which are called out in both the DOD Explosives Safety Standard[1] and in the NATO Explosives Safety Standard[10]. These calculations are presented in Table 7.

CURRENT WORK--LIMITATION AND RESTRICTIONS

Since this proposed standard is based on the Kingery hemispherical TNT surface burst curves, it will have all of the limitations as discussed above. Namely, it is based on a limited data set, it includes the effects of weather and variations in charge performance, and it does not include information on certain parameters.

Recognizing these limitations, the proposed curve fits should still be used for purposes of hazard classification (as a standard of comparison) and to relate particular explosion effects or scaled distances to a given pressure level.

The curve fits, as presented, should not be extrapolated beyond the ranges shown.

These curves are not presented as an absolute standard. Since weather effects have not been included or addressed, it is understood that low pressure measurements, where weather has a great influence, may differ significantly from this standard.

REFERENCES

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6. Kingery, C. N. and Bulmash, G., Airblast Parameters From TNT Spherical Air Bursts and Hemispherical Surface Bursts, ARBRL-TR-02555, April 1984.

7 Kingery, C. N. and Pannill, B. F., Peak Overpressure vs. Scaled Distance For TNT Surface Bursts (Hemispherical Charges), BRL Memorandum Report 1518, April 1964.

8. Swisdak, M. M., Long Range (Low Pressure) Air Blast Parameters, Minutes of the 18th DDESB Seminar, Sep 1978.

9. Explosives Hazard Classification Procedures, DLAR 8220.1, TB 700-2, NAVSEAINST 8020.8A, TO 11A-1-47, (In revision) 1994.

10. Manual of NATO Safety Principles For The Storage of Military Ammunition and Explosives, Allied Ammunition Storage and Transport Publication 1 (AASTP-1), May 1992.

TABLE 1. SIMPLIFIED KINGERY AIRBLAST COEFFICIENTS

TIME OF ARRIVAL, TOA (ms/kg^1/3)							
RANGE, Z (m/kg^1/3)	A	B	C	D	E	F	G
0.06-1.50	-0.7604	1.8058	0.1257	-0.0437	-0.0310	-0.00669	0
1.50-40	-0.7137	1.5732	0.5561	-0.4213	0.1054	-0.00929	0
TIME OF ARRIVAL, TOA (ms/lb^1/3)							
RANGE, Z (ft/lb^1/3)	A	B	C	D	E	F	G
0.2-4.5	-2.5671	1.5348	0.1313	0.01825	0.003656	-0.008615	0
4.5-100	-1.79097	-0.44021	2.01409	-0.78101	0.13045	-0.0081529	0
INCIDENT PRESSURE, PI (kPa)							
RANGE, Z (m/kg^1/3)	A	B	C	D	E	F	G
0.2-2.9	7.2106	-2.1069	-0.3229	0.1117	0.0685	0	0
2.9-23.8	7.5938	-3.0523	0.40977	0.0261	-0.01267	0	0
23.8-198.5	6.0536	-1.4066	0	0	0	0	0
INCIDENT PRESSURE, PI (psi)							
RANGE, Z (ft/lb^1/3)	A	B	C	D	E	F	G
0.5-7.25	6.9137	-1.4398	-0.2815	-0.1416	0.0685	0	0
7.25-60	8.8035	-3.7001	0.2709	0.0733	-0.0127	0	0
60-500	5.4233	-1.4066	0	0	0	0	0
REFLECTED PRESSURE, PR (kPa)							
RANGE, Z (m/kg^1/3)	A	B	C	D	E	F	G
0.06-2.00	9.006	-2.6893	-0.6295	0.1011	0.29255	0.13505	0.019736
2.00-40	8.8396	-1.733	-2.64	2.293	-0.8232	0.14247	-0.0099
REFLECTED PRESSURE, PR (psi)							
RANGE, Z (ft/lb^1/3)	A	B	C	D	E	F	G
0.3-4.0	9.0795	-1.7511	-0.2877	-0.2199	-0.0128	0.0696	-0.0118
4-100	5.1515	9.15826	-11.85735	5.56754	-1.33455	0.16333	-0.008181

FUNCTION = EXP (A+B*(LN(Z))+C*(LN(Z))^2+D*(LN(Z))^3+E*(LN(Z))^4+F*(LN(Z))^5+G*(LN(Z))^6)

RANGE, Z shown above is scaled range

A, B, C, D, E, F, G are the coefficients given above

TABLE 1. SIMPLIFIED KINGERY AIRBLAST COEFFICIENTS

(continued)

POSITIVE PHASE DURATION, T (ms/kg^1/3)							
RANGE, Z (m/kg^1/3)	A	B	C	D	E	F	G
0.2-1.02	0.5426	3.2299	-1.5931	-5.9667	-4.0815	-0.9149	0
1.02-2.80	0.5440	2.7082	-9.7354	14.3425	-9.7791	2.8535	0
2.80-40	-2.4608	7.1639	-5.6215	2.2711	-0.44994	0.03486	0

POSITIVE PHASE DURATION, T (ms/lb^1/3)							
RANGE, Z (ft/lb^1/3)	A	B	C	D	E	F	G
0.5-2.5	-1.7221	0.45	1.3552	1.1249	-0.05773	-0.608	0
2.5-7	-18.7701	55.0513	-60.4348	32.0236	-8.3256	0.8817	0
7-100	-13.0597	19.7805	-11.2975	3.2552	-0.4647	0.02624	0

INCIDENT IMPULSE, I I (kPa-ms/kg^1/3)							
RANGE, Z (m/kg^1/3)	A	B	C	D	E	F	G
0.2-0.96	5.522	1.117	0.6	-0.292	-0.087	0	0
0.96-2.38	5.465	-0.308	-1.464	1.362	-0.432	0	0
2.38-33.7	5.2749	-0.4677	-0.2499	0.0588	-0.00554	0	0
33.7-158.7	5.9825	-1.062	0	0	0	0	0

INCIDENT IMPULSE, I I (psi-ms/lb^1/3)							
RANGE, Z (ft/lb^1/3)	A	B	C	D	E	F	G
0.5-2.41	2.975	-0.466	0.963	0.03	-0.087	0	0
2.41-6.0	0.911	7.26	-7.459	2.960	-0.432	0	0
6.0-85	3.2484	0.1633	-0.4416	0.0793	-0.00554	0	0
85-400	4.7702	-1.062	0	0	0	0	0

FUNCTION = EXP (A+B*(LN(Z))+C*(LN(Z))^2+D*(LN(Z))^3+E*(LN(Z))^4+F*(LN(Z))^5+G*(LN(Z))^6)

RANGE, Z shown above is scaled range

A, B, C, D, E, F, G are the coefficients given above

TABLE 1. SIMPLIFIED KINGERY AIRBLAST COEFFICIENTS

(continued)

REFLECTED IMPULSE, IR (kPa-ms/kg^1/3)							
RANGE, Z (m/kg^1/3)	A	B	C	D	E	F	G
0.06-40	6.7853	-1.3466	0.101	-0.01123	0	0	0
REFLECTED IMPULSE, IR (psi-ms/lb^1/3)							
RANGE, Z (ft/lb^1/3)	A	B	C	D	E	F	G
0.2-100	5.9313	-1.5622	0.1322	-0.01123	0	0	0
SHOCK FRONT VELOCITY, SFV (km/s)							
RANGE, Z (m/kg^1/3)	A	B	C	D	E	F	G
0.06-1.50	0.1794	-0.956	-0.0866	0.109	0.0699	0.01218	0
1.50-40	0.2597	-1.326	0.3767	0.0396	-0.0351	0.00432	0
SHOCK FRONT VELOCITY, SFV (kft/s)							
RANGE, Z (ft/lb^1/3)	A	B	C	D	E	F	G
0.2-4.5	2.13023	-0.69169	-0.11186	-0.0578	0.0082968	0.017005	0
4.5-100	3.1767	-2.2283	0.3537	0.1059	-0.03892	0.0033157	0

FUNCTION = EXP (A+B*(LN(Z))+C*(LN(Z))^2+D*(LN(Z))^3+E*(LN(Z))^4+F*(LN(Z))^5+G*(LN(Z))^6)

RANGE, Z shown above is scaled range

A, B, C, D, E, F, G are the coefficients given above

TABLE 2. LOGARITHIMC SLOPE OF INCIDENT PRESSURE VERSUS DISTANCE

LOGARITHMIC SLOPE: INCIDENT PRESSURE-SCALED DISTANCE (kPa/(m/kg^1/3))				
RANGE, Z (m/kg^1/3)	**A**	**B**	**C**	**D**
0.2-2.9	-2.1069	-0.6458	0.3351	0.274
2.9-23.8	-3.0523	0.81954	0.0783	-0.05068
23.8-198.5	-1.4066	0	0	0

LOGARITHMIC SLOPE: INCIDENT PRESSURE-SCALED DISTANCE (psi/(ft/lb^1/3))				
RANGE, Z (ft/lb^1/3)	**A**	**B**	**C**	**D**
0.5-7.25	-1.4398	-0.563	-0.4248	0.274
7.25-60	-3.7001	0.5418	0.2199	-0.0508
60-500	-1.4066	0	0	0

SLOPE = d(LN(P))/d(LN(Z))

SLOPE = A+B*(LN(Z))+C*(LN(Z))^2+D*(LN(Z))^3

RANGE, Z shown above is scaled range

A, B, C, D are the coefficients given above

TABLE 3. SIMPLIFIED KINGERY AIRBLAST--METRIC UNITS

SCALED RANGE (m/kg^1/3)	TIME OF ARRIVAL (ms/kg^1/3)	INCIDENT PRESSURE (kPa)	REFLECTED PRESSURE (kPa)	POSITIVE PHASE DURATION (ms/kg^1/3)	INCIDENT IMPULSE (kpa-ms/kg^1/3)	REFLECTED IMPULSE (kpa-ms/kg^1/3)	SHOCK FRONT VELOCITY (km/s)	SLOPE (kpa/(m/kg^1/3)
0.2	0.037	17310.360	185301	0.243	369.5	10520	3.962	-1.342
0.3	0.066	10180	97546	0.222	215.7	5285	3.098	-1.322
0.4	0.101	6853	59549	0.234	175.1	3336	2.561	-1.445
0.5	0.143	4888	39422	0.281	166.2	2371	2.178	-1.590
0.6	0.193	3613	27381	0.378	170.9	1810	1.887	-1.726
0.7	0.250	2744	19624	0.548	183.4	1449	1.658	-1.846
0.8	0.315	2129	14390	0.818	201.5	1201	1.473	-1.949
0.9	0.387	1684	10746	1.211	223.9	1021	1.322	-2.035
1.0	0.467	1354	8152	1.720	236.3	884.7	1.196	-2.107
1.5	0.989	551.4	2511	2.148	177.4	520.7	0.808	-2.295
2.0	1.693	283.7	1058	2.053	134.6	363.8	0.623	-2.302
2.5	2.557	171.3	547.3	2.305	107.5	278.0	0.532	-2.207
3.0	3.546	115.7	330.7	2.819	92.70	224.3	0.480	-2.125
3.5	4.630	84.20	223.0	3.177	81.35	187.7	0.447	-2.002
4.0	5.785	64.89	162.6	3.436	72.42	161.2	0.425	-1.901
4.5	6.993	52.14	125.5	3.634	65.22	141.2	0.409	-1.815
5.0	8.242	43.23	100.9	3.793	59.31	125.6	0.398	-1.742
5.5	9.521	36.73	83.84	3.929	54.37	113.0	0.389	-1.679
6.0	10.82	31.81	71.37	4.048	50.19	102.7	0.383	-1.624
6.5	12.14	27.99	61.96	4.157	46.60	94.16	0.377	-1.576
7.0	13.48	24.94	54.64	4.258	43.48	86.89	0.373	-1.534
7.5	14.82	22.47	48.80	4.354	40.76	80.66	0.370	-1.498
8.0	16.18	20.42	44.05	4.445	38.35	75.25	0.368	-1.465
8.5	17.54	18.70	40.11	4.533	36.22	70.53	0.365	-1.437
9.0	18.91	17.24	36.80	4.618	34.31	66.35	0.363	-1.411
9.5	20.28	15.98	33.97	4.700	32.59	62.64	0.362	-1.389
10.0	21.66	14.89	31.54	4.779	31.04	59.33	0.361	-1.369
11.0	24.43	13.09	27.55	4.931	28.33	53.63	0.358	-1.336
12.0	27.21	11.67	24.43	5.074	26.07	48.93	0.357	-1.310
13.0	30.01	10.51	21.91	5.208	24.13	44.98	0.355	-1.290

TABLE 3. SIMPLIFIED KINGERY AIRBLAST--METRIC UNITS

(continued)

SCALED RANGE (m/kg^1/3)	TIME OF ARRIVAL (ms/kg^1/3)	INCIDENT PRESSURE (kPa)	REFLECTED PRESSURE (kPa)	POSITIVE PHASE DURATION (ms/kg^1/3)	INCIDENT IMPULSE (kpa-ms/kg^1/3)	REFLECTED IMPULSE (kpa-ms/kg^1/3)	SHOCK FRONT VELOCITY (km/s)	SLOPE (kpa/(m/kg^1/3)
14.0	32.82	9.561	19.84	5.334	22.47	41.62	0.354	-1.276
15.0	35.64	8.758	18.11	5.452	21.02	38.72	0.353	-1.265
16.0	38.47	8.074	16.64	5.563	19.75	36.19	0.352	-1.258
17.0	41.32	7.482	15.37	5.666	18.62	33.97	0.351	-1.254
18.0	44.18	6.964	14.27	5.763	17.61	32.00	0.351	-1.253
19.0	47.05	6.508	13.30	5.855	16.71	30.24	0.350	-1.254
20.0	49.93	6.102	12.44	5.940	15.89	28.67	0.349	-1.257
22.0	55.72	5.411	10.99	6.097	14.47	25.95	0.348	-1.268
24.0	61.54	4.871	9.802	6.238	13.29	23.70	0.347	-1.407
26.0	67.38	4.353	8.815	6.367	12.28	21.80	0.346	-1.407
28.0	73.22	3.922	7.979	6.487	11.41	20.17	0.345	-1.407
30.0	79.07	3.559	7.261	6.601	10.65	18.76	0.345	-1.407
32.0	84.89	3.250	6.637	6.712	9.982	17.53	0.344	-1.407
34.0	90.69	2.984	6.088	6.821	9.370	16.45	0.344	-1.407
36.0	96.44	2.754	5.602	6.932	8.818	15.49	0.344	-1.407
38.0	102.1	2.552	5.167	7.045	8.326	14.63	0.344	-1.407
40.0	107.8	2.375	4.775	7.162	7.885	13.85	0.344	-1.407
42.0		2.217			7.486			-1.407
44.0		2.077			7.126			-1.407
46.0		1.951			6.797			-1.407
48.0		1.837			6.497			-1.407
50.0		1.735			6.221			-1.407
60.0		1.342			5.126			-1.407
70.0		1.081			4.352			-1.407
80.0		0.896			3.776			-1.407
90.0		0.759			3.332			-1.407
100.0		0.654			2.980			-1.407
110.0		0.572			2.693			-1.407
120.0		0.506			2.455			-1.407
130.0		0.452			2.255			-1.407
140.0		0.408			2.084			-1.407
150.0		0.370			1.937			-1.407
160.0		0.338						-1.407

TABLE 4. SIMPLIFIED KINGERY AIRBLAST--ENGLISH UNITS

SCALED RANGE (ft/lb^1/3)	TIME OF ARRIVAL (ms/lb^1/3)	INCIDENT PRESSURE (psi)	REFLECTED PRESSURE (psi)	POSITIVE PHASE DURATION (ms/lb^1/3)	INCIDENT IMPULSE (psi-ms/lb^1/3)	REFLECTED IMPULSE (psi-ms/lb^1/3)	SHOCK FRONT VELOCITY (kft/s)	SLOPE (psi/(ft/lb^1/3)
0.5	0.028	2539	27,252	0.188	41.70	1190	13.12	-1.345
0.6	0.036	1997	20,430	0.177	31.64	867.2	11.73	-1.300
0.7	0.045	1634	15,944	0.172	26.07	669.0	10.65	-1.305
0.8	0.055	1370	12,814	0.171	22.79	537.3	9.773	-1.338
0.9	0.065	1167	10,520	0.173	20.80	444.7	9.042	-1.386
1.0	0.077	1006	8,774	0.179	19.59	376.6	8.417	-1.440
1.1	0.089	874.6	7,404	0.189	18.90	324.9	7.871	-1.497
1.2	0.102	765.9	6,307	0.204	18.58	284.5	7.390	-1.555
1.3	0.116	674.7	5,412	0.225	18.53	252.2	6.959	-1.612
1.4	0.131	597.6	4,673	0.252	18.68	225.9	6.572	-1.667
1.5	0.146	531.7	4,056	0.286	18.99	204.2	6.221	-1.720
1.6	0.163	475.1	3,537	0.329	19.44	185.9	5.902	-1.770
1.7	0.180	426.1	3,097	0.381	20.01	170.4	5.609	-1.817
1.8	0.199	383.6	2,722	0.445	20.69	157.0	5.341	-1.862
1.9	0.218	346.5	2,401	0.520	21.45	145.5	5.094	-1.904
2.0	0.238	313.9	2,124	0.610	22.30	135.4	4.867	-1.943
2.5	0.354	199.8	1,204	1.297	26.40	99.71	3.955	-2.102
3.0	0.493	134.9	727.0	1.671	24.04	78.23	3.313	-2.208
3.5	0.657	95.44	463.8	1.690	21.23	64.05	2.850	-2.273
4.0	0.844	70.28	310.6	1.624	18.75	54.04	2.510	-2.307
4.5	1.054	53.52	216.7	1.576	16.73	46.64	2.256	-2.315
5.0	1.283	41.95	156.8	1.570	15.12	40.96	2.060	-2.304
5.5	1.532	33.72	117.6	1.612	13.82	36.48	1.915	-2.277
6.0	1.800	27.71	90.99	1.699	12.77	32.85	1.802	-2.236
6.5	2.083	23.21	72.34	1.833	11.69	29.87	1.712	-2.185
7.0	2.380	19.78	58.87	2.016	11.01	27.36	1.640	-2.125
7.5	2.690	17.09	48.88	2.161	10.40	25.24	1.581	-2.131
8.0	3.011	14.92	41.30	2.276	9.854	23.42	1.531	-2.079
8.5	3.342	13.17	35.43	2.378	9.360	21.83	1.489	-2.031
9.0	3.683	11.74	30.79	2.468	8.911	20.45	1.454	-1.987
9.5	4.031	10.56	27.07	2.549	8.503	19.23	1.424	-1.945
10.0	4.387	9.562	24.04	2.621	8.129	18.14	1.397	-1.907
11.0	5.117	8.000	19.45	2.747	7.471	16.29	1.355	-1.837
12.0	5.867	6.837	16.19	2.854	6.910	14.78	1.321	-1.775
13.0	6.635	5.944	13.78	2.946	6.426	13.53	1.295	-1.721
14.0	7.416	5.242	11.95	3.029	6.005	12.46	1.274	-1.672
15.0	8.208	4.678	10.52	3.105	5.635	11.56	1.257	-1.629
16.0	9.009	4.216	9.373	3.174	5.308	10.77	1.244	-1.590
17.0	9.817	3.833	8.441	3.240	5.017	10.08	1.232	-1.555
18.0	10.631	3.510	7.669	3.302	4.756	9.480	1.222	-1.524

TABLE 4. SIMPLIFIED KINGERY AIRBLAST--ENGLISH UNITS

(continued)

SCALED RANGE (ft/lb^1/3)	TIME OF ARRIVAL (ms/lb^1/3)	INCIDENT PRESSURE (psi)	REFLECTED PRESSURE (psi)	POSITIVE PHASE DURATION (ms/lb^1/3)	INCIDENT IMPULSE (psi-ms/lb^1/3)	REFLECTED IMPULSE (psi-ms/lb^1/3)	SHOCK FRONT VELOCITY (kft/s)	SLOPE (psi/(ft/lb^1/3)
19.0	11.451	3.235	7.021	3.361	4.520	8.944	1.214	-1.495
20.0	12.274	2.998	6.470	3.418	4.307	8.464	1.207	-1.469
22.0	13.932	2.612	5.584	3.525	3.936	7.644	1.196	-1.425
24.0	15.601	2.311	4.905	3.626	3.624	6.968	1.187	-1.388
26.0	17.279	2.071	4.369	3.721	3.357	6.401	1.180	-1.358
28.0	18.965	1.874	3.935	3.812	3.128	5.919	1.175	-1.333
30.0	20.657	1.711	3.577	3.898	2.927	5.504	1.170	-1.312
32.0	22.356	1.573	3.276	3.979	2.751	5.143	1.166	-1.296
34.0	24.060	1.455	3.019	4.057	2.595	4.825	1.163	-1.283
36.0	25.770	1.352	2.798	4.131	2.456	4.545	1.160	-1.272
38.0	27.486	1.263	2.605	4.201	2.331	4.295	1.157	-1.265
40.0	29.207	1.183	2.436	4.268	2.218	4.071	1.155	-1.259
42.0	30.933	1.113	2.285	4.332	2.115	3.868	1.152	-1.256
44.0	32.665	1.050	2.151	4.393	2.021	3.685	1.150	-1.254
46.0	34.401	0.993	2.030	4.451	1.936	3.518	1.148	-1.253
48.0	36.142	0.941	1.921	4.506	1.857	3.365	1.146	-1.254
50.0	37.887	0.894	1.822	4.559	1.784	3.225	1.145	-1.257
60.0	46.667	0.710	1.436	4.793	1.492	2.666	1.138	-1.282
70.0	55.502	0.575	1.169	4.988	1.281	2.269	1.132	-1.407
80.0	64.336	0.477	0.972	5.161	1.121	1.972	1.129	-1.407
90.0	73.107	0.404	0.821	5.325	0.991	1.742	1.128	-1.407
100.0	81.752	0.348	0.700	5.488	0.886	1.559	1.129	-1.407
150.0		0.197			0.576			-1.407
200.0		0.131			0.425			-1.407
250.0		0.096			0.335			-1.407
300.0		0.074			0.276			-1.407
328.0		0.066			0.251			-1.407
350.0		0.060			0.234			-1.407
400.0		0.050			0.203			-1.407
450.0		0.042						-1.407
500.0		0.036						-1.407

TABLE 5. SIMPLIFIED FUNCTIONS (METRIC)–ERROR ANALYSIS

(NOTE: All errors shown are in percent)

SCALED RANGE (m/kg^1/3)	TIME OF ARRIVAL	INCIDENT PRESSURE	REFLECTED PRESSURE	POSITIVE PHASE DURATION	INCIDENT IMPULSE	REFLECTED IMPULSE	SHOCK FRONT VELOCITY	SLOPE
0.2	-0.192	-0.032	0.439	-0.034	-0.092	0.007	0.996	-6.015
0.3	0.252	0.156	-0.607	0.139	-0.054	0.006	-0.531	1.865
0.4	0.180	-0.346	-0.325	-0.432	-0.047	0.005	-0.692	0.390
0.5	0.024	-0.267	0.181	0.190	-0.052	0.005	-0.235	-0.693
0.6	-0.076	-0.019	0.418	0.406	-0.064	0.004	0.172	-0.848
0.7	-0.106	0.179	0.382	0.037	-0.080	0.004	0.346	-0.566
0.8	-0.088	0.275	0.207	-0.430	-0.101	0.003	0.319	-0.186
0.9	-0.044	0.279	0.023	-0.332	-0.124	0.003	0.174	0.137
1.0	0.006	0.224	-0.085	0.952	0.064	0.003	-0.012	0.353
1.5	0.092	-0.122	0.723	0.493	-0.190	0.002	-0.324	0.142
2.0	0.173	0.004	-0.185	-0.182	-0.076	0.002	0.431	-0.445
2.5	0.025	0.148	0.034	-0.041	1.514	0.002	0.098	0.180
3.0	-0.055	-0.051	0.001	0.400	0.052	0.002	-0.139	-0.865
3.5	-0.061	0.072	-0.145	-0.197	-0.389	0.002	-0.196	-0.013
4.0	-0.032	0.029	-0.254	-0.345	-0.398	0.002	-0.149	0.287
4.5	0.005	-0.043	-0.286	-0.309	-0.257	0.002	-0.061	0.349
5.0	0.036	-0.107	-0.251	-0.210	-0.094	0.002	0.027	0.330
5.5	0.054	-0.159	-0.175	-0.099	0.041	0.002	0.098	0.303
6.0	0.060	-0.202	-0.084	0.000	0.132	0.003	0.147	0.299
6.5	0.055	-0.242	0.004	0.079	0.181	0.003	0.175	0.323
7.0	0.041	-0.282	0.076	0.137	0.193	0.003	0.184	0.371
7.5	0.021	-0.324	0.124	0.176	0.177	0.003	0.180	0.433
8.0	-0.003	-0.369	0.148	0.197	0.142	0.003	0.166	0.497
8.5	-0.029	-0.415	0.146	0.205	0.094	0.003	0.145	0.554
9.0	-0.055	-0.463	0.123	0.202	0.038	0.003	0.120	0.598
9.5	-0.080	-0.510	0.083	0.190	-0.019	0.004	0.092	0.621
10.0	-0.103	-0.554	0.028	0.172	-0.075	0.004	0.064	0.621
11.0	-0.142	-0.632	-0.105	0.126	-0.175	0.004	0.008	0.552
12.0	-0.168	-0.688	-0.244	0.075	-0.250	0.004	-0.042	0.398
13.0	-0.182	-0.719	-0.366	0.025	-0.298	0.005	-0.085	0.188
14.0	-0.186	-0.726	-0.455	-0.018	-0.319	0.005	-0.121	-0.045
15.0	-0.182	-0.713	-0.506	-0.052	-0.318	0.005	-0.147	-0.263
16.0	-0.172	-0.684	-0.517	-0.076	-0.300	0.006	-0.164	-0.433
17.0	-0.158	-0.647	-0.493	-0.091	-0.270	0.006	-0.171	-0.529
18.0	-0.143	-0.608	-0.440	-0.097	-0.234	0.006	-0.169	-0.533
19.0	-0.129	-0.575	-0.367	-0.095	-0.195	0.006	-0.157	-0.434
20.0	-0.116	-0.553	-0.284	-0.086	-0.158	0.007	-0.136	-0.233
22.0	-0.102	-0.561	-0.125	-0.053	-0.098	0.007	-0.071	0.441
24.0	-0.106	-1.260	-0.026	-0.009	-0.069	0.008	0.014	-8.091
26.0	-0.128	-0.540	-0.027	0.037	-0.077	0.008	0.103	-5.392
28.0	-0.164	-0.134	-0.137	0.075	-0.122	0.009	0.178	-2.712
30.0	-0.208	0.010	-0.339	0.097	-0.194	0.009	0.221	-0.353
32.0	-0.251	-0.043	-0.582	0.097	-0.286	0.010	0.221	1.422
34.0	-0.285	-0.215	-0.792	0.071	-0.149	0.010	0.172	2.375
36.0	-0.297	-0.415	-0.868	0.012	0.057	0.010	0.079	2.252
38.0	-0.276	-0.542	-0.691	-0.081	0.246	0.011	-0.040	0.743
40.0	-0.210	-0.489	-0.126	-0.212	0.437	0.011	-0.154	-2.605
AVERAGE	-0.075	-0.295	-0.143	0.024	-0.048	0.005	0.024	-0.303
RMS AVERAGE	0.021	0.065	0.052	0.035	0.043	0.001	0.037	0.277
MAX	0.252	0.279	0.723	0.952	1.514	0.011	0.996	2.375
MIN	-0.297	-1.260	-0.868	-0.432	-0.398	0.002	-0.692	-8.091

error = 100*(kingery-this work)/kingery

TABLE 6. SIMPLIFIED FUNCTIONS (ENGLISH)--ERROR ANALYSIS

(NOTE: All errors shown are in percent)

SCALED RANGE (ft/lb^1/3)	TIME OF ARRIVAL	INCIDENT PRESSURE	REFLECTED PRESSURE	POSITIVE PHASE DURATION	INCIDENT IMPULSE	REFLECTED IMPULSE	SHOCK FRONT VELOCITY	SLOPE
0.5	0.022	-0.095	0.322	0.003	-0.022	0.000	0.564	-6.407
0.6	0.092	0.549	0.485	0.003	-0.026	0.001	0.240	-0.074
0.7	0.095	0.338	0.226	0.004	-0.029	0.002	-0.114	1.749
0.8	0.054	0.008	-0.096	0.004	-0.032	0.002	-0.326	1.757
0.9	-0.008	-0.233	-0.329	0.005	-0.035	0.003	-0.379	1.148
1.0	-0.071	-0.353	-0.439	0.005	-0.038	0.003	-0.316	0.451
1.1	-0.126	-0.374	-0.441	0.005	-0.041	0.003	-0.187	-0.127
1.2	-0.168	-0.329	-0.367	0.006	-0.044	0.003	-0.032	-0.530
1.3	-0.196	-0.246	-0.248	0.006	-0.048	0.003	0.118	-0.763
1.4	-0.209	-0.146	-0.109	0.007	-0.052	0.002	0.246	-0.859
1.5	-0.209	-0.046	0.030	0.007	-0.056	0.002	0.343	-0.853
1.6	-0.198	0.045	0.157	0.007	-0.061	0.002	0.406	-0.776
1.7	-0.179	0.123	0.265	0.008	-0.067	0.002	0.437	-0.656
1.8	-0.154	0.184	0.350	0.008	-0.072	0.001	0.440	-0.513
1.9	-0.124	0.228	0.410	0.008	-0.079	0.001	0.418	-0.361
2.0	-0.092	0.256	0.446	0.009	-0.085	0.001	0.377	-0.210
2.5	0.063	0.215	0.347	0.009	0.031	-0.001	0.056	0.339
3.0	0.145	0.044	0.029	-0.532	-0.089	-0.002	-0.182	0.468
3.5	0.136	-0.096	-0.259	0.383	-0.227	-0.004	-0.205	0.301
4.0	0.059	-0.146	-0.409	-0.055	-0.198	-0.005	-0.076	0.006
4.5	-0.050	-0.108	-0.249	-0.302	-0.128	-0.007	0.068	-0.275
5.0	0.037	-0.019	0.182	0.156	-0.112	-0.008	0.365	-0.439
5.5	-0.077	0.077	0.437	0.147	-0.182	-0.009	0.327	-0.408
6.0	-0.158	0.135	0.537	-0.253	-0.321	-0.011	0.220	-0.127
6.5	-0.207	0.112	0.523	-0.017	1.178	-0.012	0.101	0.445
7.0	-0.228	-0.026	0.437	-0.344	0.525	-0.013	-0.003	1.338
7.5	-0.227	-0.081	0.313	-0.046	0.093	-0.014	-0.084	-0.924
8.0	-0.211	0.012	0.176	-0.050	-0.179	-0.015	-0.139	-0.471
8.5	-0.185	0.050	0.041	-0.054	-0.334	-0.016	-0.171	-0.156
9.0	-0.151	0.055	-0.080	-0.058	-0.407	-0.017	-0.183	0.057
9.5	-0.115	0.041	-0.182	-0.062	-0.424	-0.018	-0.181	0.196
10.0	-0.077	0.017	-0.263	-0.066	-0.402	-0.019	-0.167	0.280
11.0	-0.004	-0.041	-0.359	-0.074	-0.299	-0.021	-0.118	0.347
12.0	0.059	-0.096	-0.379	-0.082	-0.167	-0.023	-0.059	0.345
13.0	0.108	-0.143	-0.344	-0.089	-0.043	-0.025	0.000	0.322
14.0	0.143	-0.182	-0.273	-0.096	0.059	-0.026	0.051	0.302
15.0	0.165	-0.216	-0.183	-0.103	0.132	-0.028	0.091	0.299
16.0	0.176	-0.248	-0.089	-0.109	0.179	-0.029	0.121	0.314
17.0	0.178	-0.279	0.000	-0.115	0.201	-0.031	0.142	0.345
18.0	0.173	-0.312	0.077	-0.121	0.202	-0.032	0.154	0.388
19.0	0.162	-0.346	0.139	-0.126	0.186	-0.033	0.159	0.438
20.0	0.148	-0.381	0.184	-0.132	0.161	-0.035	0.159	0.489
22.0	0.113	-0.455	0.223	-0.142	0.085	-0.037	0.147	0.576
24.0	0.078	-0.530	0.202	-0.151	-0.003	-0.039	0.127	0.621
26.0	0.047	-0.599	0.138	-0.159	-0.088	-0.041	0.104	0.608
28.0	0.023	-0.657	0.049	-0.166	-0.162	-0.043	0.079	0.537
30.0	0.009	-0.701	-0.050	-0.173	-0.219	-0.045	0.055	0.414
32.0	0.003	-0.730	-0.145	-0.179	-0.259	-0.047	0.033	0.252
34.0	0.006	-0.743	-0.227	-0.185	-0.282	-0.049	0.014	0.070
36.0	0.016	-0.741	-0.290	-0.189	-0.290	-0.050	-0.003	-0.115
38.0	0.032	-0.727	-0.330	-0.194	-0.285	-0.052	-0.017	-0.284
40.0	0.053	-0.704	-0.347	-0.198	-0.269	-0.053	-0.027	-0.422
42.0	0.077	-0.675	-0.342	-0.201	-0.245	-0.055	-0.034	-0.516
44.0	0.102	-0.644	-0.317	-0.204	-0.217	-0.056	-0.036	-0.554
46.0	0.129	-0.613	-0.277	-0.207	-0.185	-0.058	-0.034	-0.530
48.0	0.155	-0.587	-0.225	-0.209	-0.153	-0.059	-0.027	-0.441
50.0	0.181	-0.568	-0.166	-0.211	-0.122	-0.060	-0.016	-0.288
60.0	0.268	-0.655	0.084	-0.215	-0.021	-0.066	0.091	1.238
70.0	0.273	-0.161	0.013	-0.213	-0.059	-0.071	0.211	-3.011
80.0	0.218	-0.022	-0.382	-0.206	-0.212	-0.075	0.226	1.230
90.0	0.167	-0.382	-0.664	-0.195	0.021	-0.080	0.074	2.349
100.0	0.203	-0.510	-0.027	-0.181	0.397	-0.083	-0.162	-1.900
AVERAGE	0.012	-0.217	-0.033	-0.095	-0.063	-0.025	0.056	-0.048
RMS AVERAGE	0.018	0.049	0.037	0.020	0.031	0.004	0.027	0.146
MAX	0.273	0.549	0.537	0.383	1.178	0.003	0.564	2.349
MIN	-0.228	-0.743	-0.664	-0.532	-0.424	-0.083	-0.379	-6.407

error = 100*(kingery-this work)/kingery

TABLE 7. PREDICTED PRESSURE LEVELS CORRESPONDING TO SELECTED U.S. AND NATO SCALED DISTANCES

SOURCE	DESIGNATION	SCALED DISTANCE (m/kg^1/3)	SCALED DISTANCE (ft/lb^1/3)	PRESSURE (kPa)	PRESSURE (psi)
NATO	D1	0.35	0.88	8271	1200
NATO	D2	0.44	1.11	5955	863.8
NATO	D3	0.5	1.26	4888	709.0
NATO	D4	0.8	2.02	2129	308.9
NATO	D5	1.1	2.77	1104	160.2
NATO	D6	1.8	4.54	361.9	52.50
NATO	D7	2.4	6.05	187.5	27.20
NATO	D8	3.6	9.07	79.61	11.55
NATO	D9	4.8	12.10	46.44	6.737
NATO	D10	8.0	20.17	20.42	2.962
NATO	D11, Q<4500 kg	3.6	9.07	79.61	11.55
NATO	D11, Q≥4500 kg	18.8	47.39	6.595	0.957
NATO	D12	22.2	55.96	5.349	0.776
NATO	D13, Q<4500 kg	5.5	13.86	36.73	5.328
NATO	D13, Q≥4500 kg	22.2	55.96	5.349	0.776
NATO	D14	14.0	35.29	9.561	1.387
NATO	D15	18.0	45.37	6.964	1.010
NATO	D16	9.3	23.44	16.46	2.388
NATO	D17	12.0	30.25	11.67	1.692
U. S.	Intermagazine-1	0.44	1.1	6030	874.6
U. S.	Intermagazine-2	0.50	1.25	4952	718.4
U. S.	Intermagazine-3	0.79	2	2164	313.9
U. S.	Intermagazine-4	1.09	2.75	1124	163.1
U. S.	Intermagazine-5	1.59	4	484.5	70.28
U. S.	Intermagazine-6	1.79	4.5	369.0	53.52
U. S.	Intermagazine-7	1.98	5	289.2	41.95
U. S.	Barricaded Aboveground Magazine	2.38	6	191.0	27.71
U. S.	Intermagazine-8	3.17	8	102.8	14.92
U. S.	Barricaded Intraline	3.57	9	80.93	11.74
U. S.	Unbarricaded Aboveground Magazine	4.36	11	55.15	8.000
U. S.	Unbarricaded Intraline	7.14	18	24.20	3.510
U. S.	Public Traffic Route, W<100,000 lbs	9.52	24	15.93	2.311
U. S.	Public Traffic Route, W>250,000 lbs	11.90	30	11.79	1.711
U. S.	Inhabited Building, W>100,000 pounds	15.87	40	8.158	1.183
U. S.	Inhabited Building, W>250,000 pounds	19.83	50	6.166	0.894
U. S.	Public Withdrawal Distance	130.12	328	0.452	0.066