Blast Parameters From *Explosions in Air* (Coded in C++)

by Robert J. Yager

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Blast Parameters From *Explosions in Air* (Coded in C++)

Robert J. Yager
Weapons and Materials Research Directorate, ARL
This report describes a set of arrays, coded in C++, that stores information contained in Explosions in Air tables 6-3, 6-4, 6-5, and 6-6. The purpose of the code is to provide model developers with easy access to the tabulated values, which can be used to construct blast pressure histories.
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Acknowledgments

The author would like to thank Mr. Richard Pearson of the U.S. Army Research Laboratory’s Weapons and Materials Research Directorate. Mr. Pearson provided technical and editorial recommendations that improved the quality of this report.
1. Introduction

This report describes a set of arrays, coded in C++, that stores information contained in the U.S. Army Materiel Command book *Engineering Design Handbook, Explosions in Air*,\(^1\) tables 6-3, 6-4, 6-5, and 6-6. The purpose of the code is to provide model developers with easy access to the tabulated values, which can be used to construct blast pressure histories.

The symbols used in this report are the same as the symbols used in chapter 6 of *Explosions in Air* and, thus, have the same definitions.

2. Tabulated Blast Parameters

Table 1 presents blast parameters obtained from tables 6-3, 6-4, 6-5, and 6-6 of *Explosions in Air*. Noncolored cells contain values that were taken directly from *Explosions in Air*. Colored cells contain interpolated, extrapolated, or modified values.

Green cells contain interpolated values. Interpolations were performed such that they are linear on a log-log plot.

Orange cells contain values that are not meant to be reliable estimations. The values contained in the orange cells are all set to \(1.0 \times 10^9\). Setting the unknown values to extremely large values was done to assist programmers with the task of testing cell values for validity.

Yellow cells contain extrapolated values that are meant to be reliable estimations. *Explosions in Air* does not list tabulated \(\bar{r}_I\) values for \(0.06 < \bar{R}\). However, *Explosions in Air* figure 6-3 presents graphical data for \(\bar{r}_I\) well below \(\bar{R} = 0.06\). The data point \(\bar{r}_I = 53\) at \(\bar{R} = 0.01423\) was estimated based on figure 6-3. \(\bar{r}_I\) values for \(0.01423 < \bar{R} < 0.06\) were found by interpolating between \(\bar{r}_I\) at \(\bar{R} = 0.01423\) and \(\bar{r}_I\) at \(\bar{R} = 0.06\). Interpolations were performed such that they are linear on a log-log plot.

Blue cells contain modified values.

There appears to be an error in the tabulated values given in table 6-3. For \(\bar{R} = 0.016\), \(\bar{n}_s\) is stated to be 31.5. However, 31.5 is inconsistent with neighboring values; 21.5 seems likely to be the correct value.

---

Explosions in Air lists the value for $\bar{\theta}$ at $\bar{R} = 0.01423$ as exactly zero. It is common to work with logarithms of blast parameters, such as when graphing or interpolating. To avoid problems with attempting to find the logarithm of zero, at $\bar{R} = 0.01423$, $\bar{\theta}$ has been set to $1.0 \times 10^{-20}$.

Table 1. Blast parameters obtained from tables 6-3, 6-4, 6-5, and 6-6 of Explosions in Air.

<table>
<thead>
<tr>
<th>$\bar{R}$</th>
<th>$\bar{\rho}$</th>
<th>$\bar{\theta}$</th>
<th>$\bar{\psi}$</th>
<th>$\bar{\theta}$</th>
<th>$\bar{\psi}$</th>
<th>$\bar{\theta}$</th>
<th>$\bar{\psi}$</th>
<th>$\bar{\theta}$</th>
<th>$\bar{\psi}$</th>
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<td>1E+9</td>
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<td>670</td>
<td>17.7</td>
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<td>1E+9</td>
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<td>8.6022</td>
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<td>6.20</td>
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<tr>
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<td>0.740</td>
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<td>0.506</td>
<td>0.19</td>
<td>0.466</td>
<td>1.33</td>
<td>1.35</td>
<td>0.940</td>
<td>1.12</td>
<td>1.36</td>
<td>1.66</td>
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<tr>
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<td>1.12</td>
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<td>0.940</td>
<td>1.12</td>
<td>1.36</td>
<td>1.66</td>
</tr>
</tbody>
</table>

3. C++ Code

The following arrays are used to store the values presented in table 1. Each array stores one column.
3.1 \( \overline{R} \) Values: The R Array

```c
const double R[39] = { // SCALLED RANGES
    .01423, .016, .018, .02, .023, .025, .028, .031, .034, .037, .04, .043, .046, .049, .052, .055, .058, .061, .064, .067, .07, .073, .076, .079, .082, .085, .088, .091, .094, .097, .1, .103, .106, .109, .112, .115, .118, .121, .124, .127, .13, .133, .136, .139, .142,
}; // ~~~YAGENAUT@GMAIL.COM ~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~ ~~~~
```

3.2 \( \overline{P_s} \) Values: The P_s Array

```c
const double P_s[39] = { // SCALLED PEAK SIDE-ON OVERPRESSURES
    819, 703, 605, 531, 424, 325, 250, 204, 14, 15.29, 14.55, 13.81, 13, 12.1, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1.42, 1.17, 1.1, .095, .085, .076, .069, .062, .055, .049, .043, .039, .034, .03, .026, .022, .019, .016, .013, .01, .008, .006, .004, .0024, .00115
}; // ~~~YAGENAUT@GMAIL.COM ~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~ ~~~~
```

3.3 \( \overline{u_s} \) Values: The u_s Array

```c
const double u_s[39] = { // SCALLED PEAK PARTICLE SPEEDS
    23.2, 21.5, 19.8, 18.6, 14.4, 12, 10.4, 9.8912, 9.1794, 8.2599, 7.5381, 6.47, 4.61, 3.5, 2.69, 1.95, 1.25, .888, .672, .427, .302, .165, .107, .092, .0631, .0441, .0336, .0268, .019, .0144, .00621, .0039, .00279, .00217, .00177, .00128, .0011573, 8.2E-5
}; // ~~~YAGENAUT@GMAIL.COM ~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~ ~~~~
```

3.4 \( \overline{U} \) Values: The U Array

```c
const double U[39] = { // SCALLED SHOCK SPEEDS
    25.2, 23.6, 21.9, 20.6, 16.1, 13.5, 11.7, 11.163, 10.408, 9.4284, 8.6543, 7.5, 5.55, 4.27, 3.33, 2.66, 2.167, 1.48, 1.28, 1.19, 1.11, 1.0733, 1.0481, 1.0374, 1.0257, 1.00148, 1.0111, 1.0085, 1.00372, 1.00232, 1.00167, 1.00106, 1.000618, 1.000494, 1.0003988, 1.0000494
}; // ~~~YAGENAUT@GMAIL.COM ~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~ ~~~~
```

3.5 \( \overline{t_a} \) Values: The t_a Array

```c
const double t_a[39] = { // SCALLED ARRIVAL TIMES
    1E-20, 7.16E-5, 1.66E-4, 2.58E-4, 8.05E-4, .00148, .00227, .0025799, .0031215, .0040863, .0051599, .00762, .0154, .0255, .0382, .0541, .0990, .157, .218, .34, .466, .83, 1.26, 1.71, 2.2, 3.21, 4.21, 5.19, 7.15, 9.1, 18.9, 28.8, 38.9, 48.9, 58.8, 78.5, 98.5, 499, 1000
}; // ~~~YAGENAUT@GMAIL.COM ~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~ ~~~~
```

3.6 \( \overline{\rho_s} \) Values: The rho_s Array

```c
const double rho_s[39] = { // SCALLED PEAK SIDE-ON DENSITIES
    12.18, 11.9, 11.6, 11.3, 10.1, 9.28, 8.88, 8.6622, 8.3476, 7.9225, 7.5718, 7.02, 5.91, 4.92, 4.2, 3.59, 2.66, 2.09, 1.81, 1.49, 1.33, 1.17, 1.11, 1.0809, 1.0628, 1.0436, 1.0332, 1.0266, 1.0186, 1.0141, 1.0062, 1.00387, 1.00279, 1.00217, 1.00177, 1.00103, 1.000824, 1.000173, 1.0000824
}; // ~~~YAGENAUT@GMAIL.COM ~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~ ~~~~
```
3.7 \( \bar{Q} \) Values: The \( Q \) Array

```c
const double Q[39] = { //<----------------------SCALED PEAK DYNAMIC OVERPRESSURES
    4570, 3850, 3240, 2760, 1450, 935, 670, 591.18, 490.67, 377.06, 300.14, 205, 87.2, 44.1,
    20.8, 9.45, 2.79, 1.08, 57, .212, .094, .0196, .00758, .00423, .00270, .00137, .00082,
    .000515, .00025, .000143, 2.76E-5, 1.07E-5, 5.52E-6, 3.31E-6, 2.19E-6, 1.15E-6,
    6.95E-7, 2.03E-8, 4.71E-9
}; //~~~YAGENAUT@GMAIL.COM~~~~~~~~~~~~~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~~~~~
```

3.8 \( \bar{T}_s \) Values: The \( T_s \) Array

```c
const double T_s[39] = { //<-----------------SCALED PEAK SIDE-ON TEMPERATURES
    39.9, 36.7, 34.7, 33.1, 26, 21.1, 17.7, 16.37, 15.17, 13.31, 11.895, 9.85, 6.2, 4.31, 3.21, 2.48, 1.68, 1.43, 1.3, 1.18, 1.12, 1.07, 1.0436, 1.0306, 1.0247, 1.0172, 1.0134, 1.0107, 1.0075, 1.00556, 1.00248, 1.00155, 1.00112, 1.00087, 1.000709,
    1.000413, 1.00033, 1.000066, 1.000033
}; //~~~YAGENAUT@GMAIL.COM~~~~~~~~~~~~~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~~~~~
```

3.9 \( \bar{P}_r \) Values: The \( P_r \) Array

```c
const double P_r[39] = { //<------------------SCALED PEAK REFLECTED OVERPRESSURES
    1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1480, 1492.3, 1110, 860, 585, 277, 146, 88.3, 37.7, 15.3, 9.4, 6.05, 2.63, 1.31, .58, .358, .25, .188, .126, .0948, .0765, .0536, .0401, .0176, .0110, .00788, .00612, .00496, .00358, .0028, .00086, .000231
}; //~~~YAGENAUT@GMAIL.COM~~~~~~~~~~~~~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~~~~~
```

3.10 \( \bar{\rho}_r \) Values: The \( \rho_r \) Array

```c
const double rho_r[39] = { //<--------------------SCALED PEAK REFLECTED DENSITIES
    1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 37.8, 33.2, 24.4, 18.1, 13.5, 10, 6.1, 4.16, 3.14, 2.12, 1.66, 1.32, 1.22, 1.16, 1.12, 1.087, 1.0664, 1.0532, 1.0392, 1.0282, 1.0124, .007744, .00558, .00434, .00354, .00206, .00165, .00033, .000165
}; //~~~YAGENAUT@GMAIL.COM~~~~~~~~~~~~~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~~~~~
```

3.11 \( \bar{T}_r \) Values: The \( T_r \) Array

```c
const double T_r[39] = { //<-------------------SCALED PEAK REFLECTED TEMPERATURES
    1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 37.8, 33.2, 24.4, 18.1, 13.5, 10, 6.1, 4.16, 3.14, 2.12, 1.66, 1.32, 1.22, 1.16, 1.12, 1.087, 1.0664, 1.0532, 1.0392, 1.0282, 1.0124, .007744, .00558, .00434, .00354, .00206, .00165, .00033, .000165
}; //~~~YAGENAUT@GMAIL.COM~~~~~~~~~~~~~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~~~~~
```

3.12 \( \bar{I}_s \) Values: The \( I_s \) Array

```c
const double I_s[39] = { //<---------------------SCALED SIDE-ON SPECIFIC IMPULSES
    1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, .0785, .0788, .106, .103, .0885,
    .0695, .0576, .0482, .0371, .0302, .02674, .0158, .012752, .010704, .00812, .0065268,
    .00546, .00410, .00325, .00158, .0010329, .000764, .00060368, .000498, .0003694,
    .000293, 5.75E-5, 2.88E-5
}; //~~~YAGENAUT@GMAIL.COM~~~~~~~~~~~~~~~~~~~~~~~~~LAST~UPDATED~12SEP2013~~~~~~
```
3.13 \( I_r \) Values: The \( I_r \) Array

\[
\text{const double } I_r[39]=\{53, 42.0339, 33.3008, 27.0381, 23.82133, 21.308, 2.3506, 1.86, 1.27, 0.677, 0.355, 0.294, 0.222, 0.178, 0.15, 0.112, 0.0885, 0.053722, 0.029338, 0.023903, 0.0173, 0.013618, 0.0112, 0.0084, 0.0058, 0.0032, 0.00154, 0.0012116, 0.00096, 0.0007388, 0.000586, 0.000115, 0.0000576\};
\]

3.14 \( t_s \) Values: The \( t_s \) Array

\[
\text{const double } t_s[39]=\{1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 0.0206, 0.0184, 0.018033, 0.0175, 0.0175, 0.0191, 0.0341, 0.0885, 0.157, 0.171, 0.158, 0.162, 0.232, 0.268, 0.31953, 0.362, 0.38687, 0.40846, 0.445, 0.47186, 0.495, 0.532, 0.564, 0.666, 0.73104, 0.781, 0.82142, 0.856, 0.9131, 0.96, 1.24, 1.25\};
\]

3.15 \( t_r \) Values: The \( t_r \) Array

\[
\text{const double } t_r[39]=\{1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 0.014, 0.016018, 0.018, 0.0219, 0.0315, 0.0425, 0.0542, 0.0684, 0.103, 0.147, 0.195, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9\};
\]

3.16 \( b \) Values: The \( b \) Array

\[
\text{const double } b[39]=\{1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1E9, 1.5, 15, 15, 16, 16, 17, 12.9, 6.76, 4.56, 3.87, 3.48, 3.08, 2.523, 2.19, 2.0597, 1.959, 1.81, 1.8264, 1.84, 1.83, 1.87, 2.17, 2.3848, 2.55, 2.7214, 2.87, 3.0782, 3.25, 3.9, 3.67\};
\]

4. Example: Recreating Figure 6-1 From Explosions in Air

The following example uses the \( R, P_s, u_s, U, t_a, \rho_s, Q, \) and \( T_s \) arrays to create a text file that contains the information necessary to recreate figure 6-1 from Explosions in Air. Figure 1 presents a graph of the contents of the example’s output file.

Note that there is an error on the original graph: the far-right label for the \( \bar{\theta}_s \) line is given as 10 \( \bar{\theta}_s \).
```c
#include <cstdio>
#include "y_blast_eia.h"

int main()
{
  FILE *f=fopen("figure_6_1.csv","w",stdout);
  printf("#R_bar,P_bar_s,10^4*P_bar_s,10^5*u_bar_s,10^2*U_bar,
          10*t_bar_a,10^5*t_bar_a,10*rho_bar_s,Q_bar,10^4*Q_bar,10^8*Q_bar,
          10^12*Q_bar,theta_bar_s\n");
  for(int i=0;i<39;++i)
  {
    printf("%e,,",yBlastEia::R[i]);
    printf("%e,,",yBlastEia::P_s[i]);
    printf("%e,,",yBlastEia::P_s[i]*1E4);
    printf("%e,,",yBlastEia::u_s[i]*10);
    printf("%e,,",yBlastEia::u_s[i]*1E5);
    printf("%e,,",yBlastEia::U[i]*1E2);
    printf("%e,,",yBlastEia::t_a[i]*10);
    printf("%e,,",yBlastEia::t_a[i]*1E5);
    printf("%e,,",yBlastEia::rho_s[i]*10);
    printf("%e,,",yBlastEia::Q[i]);
    printf("%e,,",yBlastEia::Q[i]*1E4);
    printf("%e,,",yBlastEia::Q[i]*1E8);
    printf("%e,,",yBlastEia::Q[i]*1E12);
    printf("%e\n",yBlastEia::T_s[i]);
  }
  fclose(f);
}
```

---

**Figure 1.** Recreation of figure 6-1 from *Explosions in Air.*
5. Example: Recreating Figure 6-2 From Explosions in Air

The following example uses the R, P_r, rho_r, and T_r arrays to create a text file that contains the information necessary to recreate figure 6-2 from Explosions in Air. Figure 2 presents a graph of the contents of the example's output file.

```c
#include <cstdio>
#include "y_blast_eia.h"

int main(){
    FILE *f=fopen("figure_6_2.csv","w",stdout);
    printf("#R_bar,P_bar_r,10^4*P_bar_r,rho_bar_r,10*theta_bar_r\n");
    for(int i=0;i<39;++i){
        printf("%e,",yBlastEia::R[i]);
        printf("%e,",yBlastEia::P_r[i]);
        printf("%e,",yBlastEia::P_r[i]*1E4);
        printf("%e,",yBlastEia::rho_r[i]);
        printf("%e\n",yBlastEia::T_r[i]*10);}
    fclose(f);
}
```

Figure 2. Recreation of figure 6-2 from Explosions in Air.
6. Example: Recreating Figure 6-3 From Explosions in Air

The following example uses the R, I_s, I_r, t_s, t_r, and b arrays to create a text file that contains the information necessary to recreate figure 6-2 from Explosions in Air. Figure 3 presents a graph of the contents of the example’s output file.

Note that there is an error on the original graph: the line that is labeled $b \times 10^3$ should actually be labeled $b \times 10^{-3}$.

```c
#include <cstdio>
#include "y_blast_eia.h"

int main(){
    FILE *f=fopen("figure_6_3.csv","w",stdout);
    printf("#R_bar,I_bar_s,I_bar_s*10^4,I_bar_r*10^-5,I_bar_r*10^-1,I_bar_r*10^3,
           T_bar_s*10^-2,T_bar_r*10^-2,b*10^-3\n");
    for(int i=0;i<39;++i){
        printf("%e,",yBlastEia::R[i]);
        printf("%e,",yBlastEia::I_s[i]);
        printf("%e,",yBlastEia::I_s[i]*1E4);
        printf("%e,",yBlastEia::I_r[i]*1E-5);
        printf("%e,",yBlastEia::I_r[i]*1E-1);
        printf("%e,",yBlastEia::I_r[i]*1E3);
        printf("%e,",yBlastEia::t_s[i]*1E-2);
        printf("%e,",yBlastEia::t_r[i]*1E-2);
        printf("%e\n",yBlastEia::b[i]*1E-3);}
    fclose(f);
}
```

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7. Summary

A summary sheet is provided at the end of this report. It presents the yBlastEia namespace, which contains the 16 arrays that are described in this report.
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