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A COMPUTER PROGRAM FOR FRAGMENTATION TEST DATA REDUCTION (U)

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and
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Warhead and Terminal Ballistics Laboratory

Approved by:

RALPH A. NIEMANN, Director
Computation and Analysis Laboratory

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A detailed description is given of a computer program for the reduction of fragmentation data obtained from static detonation of warheads in a test arena, including input format, a listing of the FORTRAN IV program deck, and a sample of the output from the program.
FOREWORD

The computer program described in this report was prepared in the Ballistic Sciences Branch of the Computer Programming Division, Computation and Analysis Laboratory, by Miss Beverly A. Cooper. The work was performed under the authority of NWL Technical Assistance Request for Project No. T-06AD by the Computation and Analysis Laboratory in support of the Warhead Supporting Research Program being conducted by the Warhead and Terminal Ballistics Laboratory.
INTRODUCTION

The U. S. Naval Weapons Laboratory is currently preparing a hand- 
with the Warhead Supporting Research Program established in accordance 
with Bureau of Naval Weapons Task Order No. RMMO-42-003/210-1/F008-08-06. 
The objective of this handbook is to provide systematic documentation 
of kill mechanism technology, target vulnerability data, and warhead 
terminal ballistic performance data. To be included, is a section on 
the terminal ballistic performance characteristics of bombs, projectiles, 
and rocket and missile warheads of current tactical interest to 
the Navy. A preliminary edition of this section, published as NAVWEPS 
Report No. 7673, is currently being revised to include data recently 
aquired through an extensive warhead test program conducted at the 
U. S. Naval Weapons Laboratory.

A significant portion of this program was a series of arena tests 
of statically fired warheads to establish measurements of the fragmenta-
tion characteristics--velocity, density, mass, and spatial distribution of fragments--for each of several warheads. Typically, these 
tests are performed in a field arena similar to the one described in 
Figure 1. The arena consists of two 180-degree circular sectors. One 
sector is constructed from 22-gauge mild steel plate, and the other is 
constructed of celotex panels. The warhead to be tested is positioned 
on a stand at the center of the arena with its axis horizontal and 
intersecting the sides of the arena where the two sectors meet, with 
the forward end of the warhead aimed at the 0-degrees position on the 
wall. A ricochet fence is built about the stand between the warhead 
and the arena to prevent fragments that strike the ground from reaching 
the wall panels.

High-speed motion picture cameras are placed about the steel sec-
tor to record impacts of fragments from the detonated warhead on the 
arena plates. A kilocycle/second timing trace is superimposed on the 
film in each camera during operation to allow for the determination of 
the time lapse from detonation to impact. Given the resulting time 
data and the distance from the warhead to the arena plate, an estimate 
of the average velocity of the fragments can be obtained. Fragments 
impacting on the celotex sector are recovered upon completion of the 
test, weighed, and categorized by mass interval to obtain estimates 
of the fragment number and mass distribution associated with the war-
head.

A spatial distribution of the fragments is constructed by tabu-
lating the above data for each five-degree polar zone (angular inter-
val measured from horizontal axis of warhead).
FIGURE 1. TYPICAL ARENA SET-UP
DATA REDUCTION

To facilitate and expedite reduction of the raw test data to a useful and meaningful form, a high-speed computer program was formulated and coded in FORTRAN IV for execution on an IBM 7030 computer.

The flow chart given as Figure 2 outlines the major features of the program. For each mass interval (weight group) within a polar zone, the fragment density and average mass are computed. Upon completion of these computations, initial fragment velocity, total fragment weight, and number of fragments per steradian for the polar zone are calculated. Each zone is considered in succession until the total fragment space has been spanned. These output are then tabulated as shown in Figure A-3.

a. The fragment density for each mass interval is obtained by scaling the average number of fragments recovered by the value computed from the equation:

\[
\frac{A_k}{a_k} = \frac{2\pi (\cos \theta_{k+1} - \cos \theta_k)}{\int_{\theta_k}^{\theta_{k+1}} \sin \theta \arcsin \left( \frac{\sin x}{\sin \theta} \right) \, d\theta}
\]

where,

\[
\arctan x = \frac{H}{2r}
\]

\[r = \text{radius of mass arena, feet}\]
\[H = \text{height of mass arena, feet}\]
\[\theta_k = \text{angular distance from horizontal axis of warhead to the lower bound of k-th polar zone}\]

The average mass is simply the total weight of the recovered fragments divided by the number of fragments.
Figure 2. Flow Chart
b. The initial fragment velocity for the polar zone is determined from the equation,

\[ V = \bar{V} \left( e^{\frac{w}{e}} - 1 \right) \]

\( V \) = initial fragment velocity, feet/second
\( \bar{V} \) = average fragment velocity, feet/second
\( e \) = base of natural logarithm

and,

\[ w = 0.489 \rho_a C_d R \left( \frac{\bar{A}}{M} \right) \]

for,

\( \rho_a \) = air density, pounds/feet\(^3\)
\( C_d \) = drag coefficient
\( R \) = radius of velocity arena, feet
\( \left( \frac{\bar{A}}{M} \right) \) = area mass ratio, centimeters\(^2\)/grams.

The value of the area mass ratio is given by the relationship,

\[ \left( \frac{\bar{A}}{M} \right) = b(m)^{-c} \]

where,

\( b \) = fragment area mass constant
\( c \) = fragment area mass exponent
\( m \) = fragment mass, which in this case is the average fragment mass taken over the entire polar zone.
c. The total fragment weight per polar zone is obtained by merely summing the product of the number of fragments and the average fragment weight for each mass interval over the total polar zone.

d. The steradian measure of the polar zone is,

$$A_k = 2\pi (\cos \theta_{k+1} - \cos \theta_k)$$

where $\theta_k$ is as defined in subparagraph a, above. Dividing the total number of fragments in the polar zone by $A_k$ yields the number of fragments per steradian for the zone.

The remainder of the pertinent fragmentation data—heaviest fragment recovered and the number of hits (fragment impacts on velocity arena wall) from which the average velocity is calculated—is obtained by observing the raw test data. These values are inserted manually in the spaces provided in the output format. The total process is then repeated for each successive polar zone until the total fragment space has been spanned.

A listing of the program deck, the input format, and a sample of the input and output from the program are included in Appendix A.
PROGRAM DECK

A listing of the FORTRAN IV program deck designed for execution on the IBM 7030 is given as Figure A-1.

INPUT FORMAT

A description of the input format is shown in Figure A-2, and the various input data required by the program identified below:

<table>
<thead>
<tr>
<th>Card Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Card Type 1</td>
<td>NRUNS</td>
</tr>
<tr>
<td>Card Type 2</td>
<td>INT</td>
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<tr>
<td></td>
<td>NZONE</td>
</tr>
<tr>
<td></td>
<td>MULT</td>
</tr>
<tr>
<td>Card Type 3</td>
<td>TAB</td>
</tr>
<tr>
<td></td>
<td>WEAP</td>
</tr>
<tr>
<td>Card Type 4</td>
<td>EXPLO</td>
</tr>
<tr>
<td></td>
<td>REFNO</td>
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<tr>
<td></td>
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</tr>
<tr>
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</tr>
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<td>H</td>
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<td>Card Type 5</td>
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</tr>
<tr>
<td></td>
<td>CD</td>
</tr>
<tr>
<td></td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Card Type 6</td>
<td>NFRAG</td>
</tr>
</tbody>
</table>

Starting with the first polar zone, list the number of fragments in the largest mass interval, the next largest mass interval, etc., until all mass intervals have been accounted for. Continue listing in the same order for each successive polar zone until all polar zones have been considered.
PROGRAM TO EDIT FRAGMENTATION DATA

DIMENSION NFRAG(20,36), W(2,36), VBAR(36), THETA(37), AK(37), C(37), CNBAR(20,36), CMBAR(20,36), NO(36), VO(36), V(36), INT(20,36), RAD(37), 2ND(10), EXPLO(5), FRAG(20,36), REFNO(2), ASIN(37), WBAR(36)

EQUIVALENCE (NFRAG, FRAG)

FOR I = 1 TO 10
10 FORMAT(15,15,3F5.1)
11 FORMAT(15,15,3F5.1)
12 FORMAT(15,15,3F5.1)
13 FORMAT(15,15,3F5.1)
14 FORMAT(15,15,3F5.1)
15 FORMAT(15,15,3F5.1)
16 FORMAT(15,15,3F5.1)
17 FORMAT(15,15,3F5.1)
18 FORMAT(15,15,3F5.1)
19 FORMAT(15,15,3F5.1)
20 FORMAT(15,15,3F5.1)
21 FORMAT(15,15,3F5.1)
22 FORMAT(15,15,3F5.1)
23 FORMAT(15,15,3F5.1)
24 FORMAT(15,15,3F5.1)
25 FORMAT(15,15,3F5.1)
26 FORMAT(15,15,3F5.1)
27 FORMAT(15,15,3F5.1)
28 FORMAT(15,15,3F5.1)
29 FORMAT(15,15,3F5.1)
30 FORMAT(15,15,3F5.1)
31 FORMAT(15,15,3F5.1)

READ 13, NRUNS, THETA(1) = 0.0, RAD(1) = 0.0, ASIN(1) = 0.0
DO 400 LL = 1, NRUNS
READ 13, INT, NZONE, IMULT
READ 10, Tag, WEAP
READ 11, EXPLO, REFNO, NR, RADM, R, H
READ 12, RHOA, CD, B, C
READ 15, (INFRAG(I,J), INT), J = 1, NZONE
READ 16, (INT(I,J), INT), J = 1, NZONE
READ 14, (VBAR(J), J = 1, NZONE)
READ 14, (AIN(I), I = 1, INT)
AMULT = IMULT
SX = H/SQRT((MM+4)*RADM*RADN)
CX = SQRT(SX*SX)
X = ARTN0(SX CX)
XD = X*57.2957795131
NZ = NZONE + 1
DO 100 M = 2, NZ
THETA(M) = THETA(M-1) + 5.0*AMULT
100 FORMAT(15,15,3F5.1)

Figure A-1. Program Deck Listing.
PRINT 26
PRINT 27
PRINT 28
PRINT 29, (AIN(I-1), AINT(I), I=8, INT)
DO 302 J=1, NZONE
302 PRINT 30, (CMBAR(I,J), CMBAR(I,J), I=8, INT), VBAR(J), VO(J), WBAR(J), 1NO(J)
PRINT 31, WSV
400 CONTINUE
RETURN
END
program 489*rhoa*cd*r
anr=nr
wsun=0.0
ist=0
100 do 300 j=1,nzone
j=j+1
div=sx/sin(rad(jj))
div1=sort1(1)-div*div1)
ason=aptrn(div+div1)
if(sx*ge*sin(rad(jj))*.and..sx*ge*sin(rad(jj))) go to 140
if(sx*le*sin(rad(jj))*.and..sx*le*sin(rad(jj))) go to 130
if(ist.eq.1) go to 131
ak(jj)=theta(jj)-theta(j)
degx=acos(xd-theta(jj))+(6.28318531*abs(cos(rad(jj))-cx)
1*(theta(jj)-xd)/((rad(jj)-x)*(sin(rad(jj)))*asin(jj)+sx*1.5707963)
2)
1 ist
1 save=ak(jj)
1 savec=cak(jj)
go to 142
131 ak(jj)=save
1 cak(jj)=savec
go to 142
140 ak(jj)=(cos(rad(j))-cos(rad(jj)))*3.14159265
go to 141
13 ak(jj)=(sin(rad(jj))+sin(rad(jj))*asin(jj))*rad(jj)-rad
1(jj)
141 cak(jj)=6.2831531*(cos(rad(j))-cos(rad(jj)))
142 cb=ck(j)/ak(jj)
1 cak(jj)=6.2831531*(cos(rad(j))-cos(rad(jj))
150 u=0.0
1 wbar(j)=0.0
1 snbar=0.0
1 smb=0.0
200 do 200 i=1,int
2 cnbar(i,j)=cb*(frag(i,j)/anr)
2 cmbar(i,j)=w(i,j)/frag(i,j)
2 wbar(j)=cnbar(i,j)+cmar(i,j)+wbar(j)
2 if(cmbar(i,j)) 2212219220
210 u=u+1.0
2 skb=cmbar(i,j)+smb
221 if(cmbar(i,j)) 200220220
22 u snbar=cmbar(i,j)+snbar
200 continue
2 snbar=(i1/u1)*smb
2 abar=b+(snbar*-1./c)
2 omegax=probabar
2 vo(j)=wbar(j)*(v2.71821828459**omegax-1.)/omegax
2 no(j)= snbar/cak(jj)
2 wsum=wsun+wbar(j)
300 continue
3 print 20*tabs=weap
3 print 21*nr+radm*r+n+explore+refno
3 print 22
3 print 23+a1nt(i),a1nt(i+1),i=1,6
3 print 24
3 do 301 j=1,nzone
301 print 25>theta(jj)+theta(jj+1),(cnbar(i,j)+cmar(i,j))=1,7

figure a-1 (cont'd)
Card Type 7  W  Total weight of fragments per mass interval per zone

Starting with the first polar zone, list the total weight of the recovered fragments in the largest mass interval, the next largest mass interval, etc., until all mass intervals have been accounted for. Continue listing in the same order for each successive polar zone until all polar zones have been considered.

Card Type 8  VBAR  Average fragment velocity per zone

Starting with the first polar zone, list the average fragment velocity, and continue listing for each successive polar zone until all have been considered.

Card Type 9  AINT  Mass interval

Starting with the largest mass interval, list the value of the lower bound, and continue listing until all mass intervals have been considered. Since all polar zones have the same mass intervals, they are listed only once.

INPUT AND OUTPUT

A sample of the input and output from the program is presented in Figures A-3 and A-4. This table is based on data from static detonation tests of four 8'/55 Mk 25 Mod 1 (HC) projectile warheads.
### CARD TYPE 7

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### CARD TYPE 8

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### CARD TYPE 9

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<td>XX XX XX XX XX</td>
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</tr>
<tr>
<td>XX XX XX XX XX</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure A-2 (Cont'd.)

CONFIDENTIAL
Figure A-3. Sample Input.
|    | 7.9  | 8.0  | 8.1  | 8.2  | 8.3  | 8.4  | 8.5  | 8.6  | 8.7  | 8.8  | 8.9  | 9.0  | 9.1  | 9.2  | 9.3  | 9.4  | 9.5  | 9.6  |
|----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|  J | 34.5 | 34.6 | 34.7 | 34.8 | 34.9 | 35.0 | 35.1 | 35.2 | 35.3 | 35.4 | 35.5 | 35.6 | 35.7 | 35.8 | 35.9 | 36.0 | 36.1 |
|  D | 31.2 | 31.3 | 31.4 | 31.5 | 31.6 | 31.7 | 31.8 | 31.9 | 32.0 | 32.1 | 32.2 | 32.3 | 32.4 | 32.5 | 32.6 | 32.7 | 32.8 |
|  C | 27.7 | 27.8 | 27.9 | 28.0 | 28.1 | 28.2 | 28.3 | 28.4 | 28.5 | 28.6 | 28.7 | 28.8 | 28.9 | 29.0 | 29.1 | 29.2 | 29.3 |
|  B | 9.6  | 9.7  | 9.8  | 9.9  | 10.0 | 10.1 | 10.2 | 10.3 | 10.4 | 10.5 | 10.6 | 10.7 | 10.8 | 10.9 | 11.0 | 11.1 | 11.2 |
|  A | 30.6 | 30.7 | 30.8 | 30.9 | 31.0 | 31.1 | 31.2 | 31.3 | 31.4 | 31.5 | 31.6 | 31.7 | 31.8 | 31.9 | 32.0 | 32.1 | 32.2 |
|    | 6.0  | 6.1  | 6.2  | 6.3  | 6.4  | 6.5  | 6.6  | 6.7  | 6.8  | 6.9  | 7.0  | 7.1  | 7.2  | 7.3  | 7.4  | 7.5  | 7.6  |

Figure A-3 (Cont'd)
### Fragment Weight Groups (Grams)

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<tr>
<th>Polar Zone</th>
<th>11,000-12,000</th>
<th>9,000-10,000</th>
<th>7,000-8,000</th>
<th>5,000-6,000</th>
<th>3,000-4,000</th>
<th>2,000-3,000</th>
<th>1,000-2,000</th>
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<td>-0.00</td>
<td>-0.00</td>
<td>-0.00</td>
<td>-0.00</td>
<td>-0.00</td>
</tr>
<tr>
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<td>-0.00</td>
<td>-0.00</td>
<td>-0.00</td>
<td>-0.00</td>
<td>-0.00</td>
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</tr>
<tr>
<td>10-15</td>
<td>0.628</td>
<td>42.500</td>
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<td>-0.00</td>
<td>-0.00</td>
<td>-0.00</td>
<td>-0.00</td>
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<td>-0.00</td>
<td>-0.00</td>
<td>-0.00</td>
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<td>-0.00</td>
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</tr>
<tr>
<td>40-45</td>
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<td>-0.00</td>
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**M** = average number of fragments per total polar zone.

**N** = average fragment mass (grams).

**V** = distance of fragment flight/time of flight.

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**Figure A-4 (Cont'd)**

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