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COMPUTATION OF WEIGHT, VELOCITY, AND ANGULAR DISTRIBUTIONS OF FRAGMENTS FROM NATURALLY FRAGMENTING WEAPONS

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A two space dimension, time dependent fluid dynamic computer program written specifically for weapon design and analysis work is described. Metal casings are treated as sets of mass points whose motion is found along with the gas flow. The gas dynamics following detonation of the explosive is Lagrangian, with provision for slippage along the metal boundary. The program, written in BASIC, is simple and quick to run and does not require

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20. an experienced programmer.

Provision is made for calculating fragment numbers, weight distributions, and average velocities in the polar zones surrounding the weapon. These are obtained from the fluid dynamic calculations combined with fragment weight distributions assigned to the mass points. Calculated results for the 105 and 155 mm projectiles are listed. A complete list of the program, with notes, is included.

NOLTR 74-77 17 July 1974

COMPUTATION OF WEIGHT, VELOCITY, AND ANGULAR DISTRIBUTIONS OF FRAGMENTS FROM NATURALLY FRAGMENTING WEAPONS

This is the second, and final, report covering a one man year effort to construct a scheme for the rapid calculation of fragment directions, velocities, and weight distributions from naturally fragmenting weapons. It is expected that the program described here will find general use in the design of new weapons and in the analysis of existing arena test data.

The work was supported by the U. S. Army Materiel Systems Analysis Agency, under Task NOL-989/A, Fragment Prediction Method.

ROBERT WILLIAMSON II
Captain, USN
Commander

D. C. HORNIG
By direction

CONTENTS

ILLUSTRATIONS

TABLES

I INTRODUCTION

The performance of a naturally fragmenting weapon depends upon the number of fragments produced by the detonation of the high explosive (HE), their angular and weight distributions, and their velocities. Calculation of these quantities, in place of experimental firing and data collection, is especially attractive when configurations and explosives for new or improved weapons are being considered. The computational scheme described here was constructed during the past year, under U.S. Army support[1]. There are two major related parts, the computational fluid dynamics to produce the detonation wave and find the gas and metal motion, and a fragment prediction scheme to get the number, weight distribution and average velocity of fragments in each of the polar zones around the weapon. The computer program, while rather long, is in BASIC (Beginners All Purpose Symbolic Instruction Code), takes very little time to run on a large computer, and does not require an experienced programmer.

The fluid dynamics are discussed in Sec.II. A conventional Lagrangian scheme with artificial viscosity is used for the interior gas dynamics. Gas grid points are made to slide along the metal boundary by essentially the method in the HEMP code[2], but the slide point acceleration formulas are different. The standard subdivision of the metal casing into cells for which detailed calculations are made is not used. Instead, the metal is taken to be a set of mass points whose motion is a boundary condition which is solved for along with the gas flow. This avoids the inevitable difficulties which

[1] Fragment Prediction Method, Work Unit No. NOL-989/A, for U.S. Army Materiel Systems Analysis Agency, Aberdeen Proving Ground.

[2] Mark L. Wilkins, "Calculation of Elastic-Plastic Flow," in Methods of Computational Physics, Vol. 3, edited by B. Alder, S. Fernbach, and M. Rotenberg, Academic Press, New York, 1964.

arise in the usual Lagrangian scheme as the metal becomes thinner and smaller computational time steps are called for. The mass point idea is well suited to problems where the metal casing is relatively thick and expansions to 2 or 3 initial radii are calculated. Since there is a large saving in computing time if the computational grid is coarse, some attention was given to the establishment of a reasonable detonation wave in a coarse grid, and to the effect of grid size on accuracy.

The calculated results are to be used for lethal area studies which are generally made with data obtained experimentally in arena tests[3]. These data consist of numbers, weight distributions, and average velocities of fragments in 5 degree polar zones surrounding the weapon. Section III contains the scheme for producing these data analytically, by adding the calculated contributions of all the mass points to each polar zone. Fragment weight distributions assigned at the outset to each of the metal mass points are used here in conjunction with the calculated mass point motions. Results of computations for the 105 mm, M1, and 155 mm, M107, projectiles, filled with military grade Composition B explosive are given in Sec. IV. There is also provision for providing these results in other formats, for example, as a punched card deck which can be used directly in the JMEM lethal area program.

The complete BASIC computer program appears in the appendix, together with notes, a list of variables, and lists of input and output statements.

The scheme can be used for other fragmenting systems, e.g., bombs and warheads. However, in many cases fragment weight distributions and detonation product equation of state data needed to make the calculation will not be available. These data will have to be assembled, either from existing test data for various types of casings and explosives, or from new theoretical and experimental work. The program can be used, in conjunction with the arena test

---

[3] Joint Munitions Effectiveness Manual, Test Procedures for High Explosive Munitions, TH-61A1-3-7, FM101-51-3, NAVAIR00-130-ASR-2-1, FMFM5-2L, 12 Jun 1970.

data, to find the effects of various factors on fragmentation, since it provides a way to tell what parts of the casing the fragments came from, and the related detonation wave impact angle and acceleration history.

A computer program to make this kind of calculation was constructed by Lindemann[4], who used simple approximate formulas for the casing motion, in place of the computational fluid dynamics. Detailed hydrodynamic calculations have also been made with modern Lagrangian and Eulerian programs which take into account elastic-plastic flow in the metal[2,5]. The program constructed here (Appendix A) is a compromise. It has enough detail to produce useful input data for lethal area calculations. At the same time it is simple and fast enough to be operated, on a routine basis, by weapon designers and test personnel with no special interest in computer programming.

[4] Michael J. Lindemann, "A Computational Method for Predicting from Design Parameters the Effective Lethal Area of Naturally Fragmenting Weapons," Naval Ordnance Station, Indian Head, Maryland, IHTR 295, 30 Jun 1969.

[5] L.J. Hageman and J.M. Walsh, "HELP, A Multi-Material Eulerian Program For Compressible Fluid and Elastic-Plastic Flows in Two Space Dimensions and Time," Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, BRL-CR39, May 1971, (VOL I-726459; VOL II-726460).

II FLUID DYNAMICS

A. Input and Initialization

The program is designed to deal with axisymmetric systems of the type shown in Fig.1, i.e., relatively heavy casings, with closed ends, filled with HE. In view of the axial symmetry we will be concerned with half the cross section. In Fig.1, the interior has been divided into cells, while the masses of the bands of metal indicated by the broken lines have been assigned to mass points located on the interior metal boundary.

Input for the computation consists of values of K1 and L1, the number of computational grid points in the axial (Z) and radial (R) directions, dimensions of the metal casing, material densities, the detonation velocity D, various other constants, equation of state data for the gaseous detonation products, and for each mass point a fragment weight distribution (numbers of fragments per gram in various weight ranges), or, preferably, a parameter value from which this weight distribution can be calculated.

Let Z and R be the fixed grid coordinates and U and V the velocity components in the axial and radial directions, respectively. Denote the time by T, the pressure by P1, the artificial viscosity by Q1, the density by ρ, the density of the undetonated HE by ρ_o, the relative specific volume by $V1 (= \rho_o/\rho)$, and the internal energy times ρ_o by E2. Also let $2\pi W$ be the mass associated with a grid point, and $2\pi W1$ the mass associated with a cell, where A and A1 are the corresponding areas. The flow variables Z,R,U,V,W,A will be located at the grid points, while P1,Q1,V1,E2,R1,Z1,W1, will be located at the cell centers. The quantities W and W1 (mass/2π) will be called scaled masses.

The construction of the computation grid proceeds as follows (see Fig.2): Let the outer metal boundary consist of the grid points

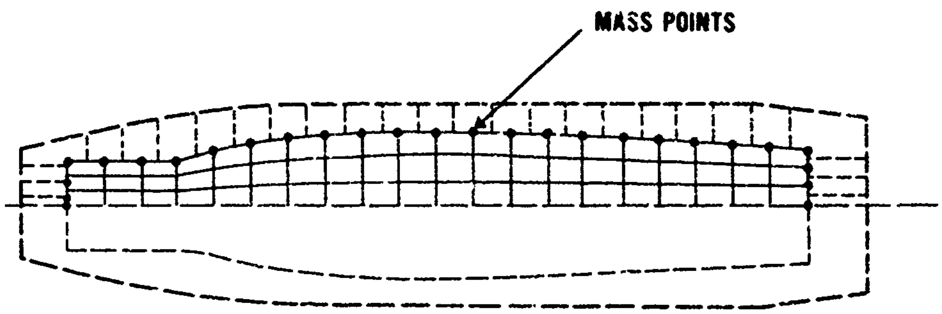

FIG. 1 COMPUTATION GRID

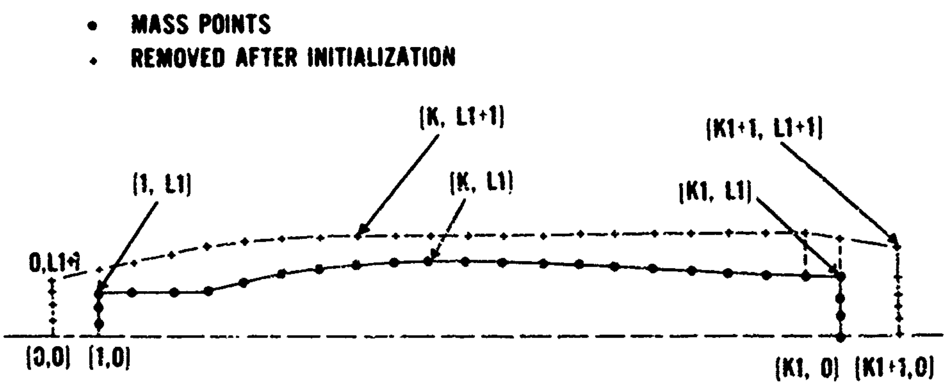

FIG. 2 BOUNDARY POINT NOTATION

(O,L) and (K1+1,L) for L=O to L1, } outer metal
(K,L1+1) for K=O to K1+1. } boundary.

These points will be used only in the calculation of the scaled masses $W_{K,L}$ to be associated with the metal mass points. The inner surface of the metal casing will contain the boundary grid points used in the computation, namely,

(1,L) and (K1,L) for L=O to L1-1, } inner metal
(K,L1) for K=1 to K1. } boundary.

Then,

a) Insert values of $Z_{0,0}$, $Z_{1,0}$, $Z_{K1,0}$, $Z_{K1+1,0}$.

b) Calculate uniformly spaced interior axis points

$$Z_{K,0} = Z_{1,0} + (Z_{K1,0} - Z_{1,0}) \cdot (K-1)/(K1-1).$$

c) Initialize the remaining Z by putting

$$Z_{K,L} = Z_{K,0} \text{ for } K=0 \text{ to } K1+1,\ L=0 \text{ to } L1+1.$$

d) Read in $R_{K,L1}$ and $R_{K,L1+1}$ for K=O to K1+1.

e) Initialize uniformly spaced R values by putting

$$R_{K,L} = R_{K,L1} \cdot L/L1, \quad \text{for } K=0 \text{ to } K1+1,\ L=0 \text{ to } L1-1$$

It is assumed above that the end walls of the weapon are perpendicular to the axis. If these walls are curved, special grid point values must be read in. An example is the base of the 105 mm projectile, for which the grid is shown in Fig.3.

Coordinates of the interior cell centers, $Z1_{K,L}$ and $R1_{K,L}$ are gotten by averaging coordinates of the four cell corners.

In order to prevent large distortions of the mesh, the grid lines extending upward from the line L=L1-1 are allowed to slide along the line L=L1. The intersections with the line L=L1, are denoted by $Z3_K$, $R3_K$. The notation $Z_{K,L1}$, $R_{K,L1}$ is used for the metal mass points. At the outset $Z3_K = Z_{K,L1}$ and $R3_K = R_{K,L1}$. At the ends, $Z3_1 = Z_{1,L1}$, $R3_1 = R_{1,L1}$, $Z3_{K1} = Z_{K1,L1}$, $R3_{K1} = R_{K1,L1}$ throughout the calculation. This notation and the variable locations are shown in Fig.4.

There is provision for an inert compressible material, with its own density and equation of state, to occupy the space between the lines K=1 and K=K4+1, where K4 is an integer specified as part of the initial conditions. This takes into account the fuze mechanism, if

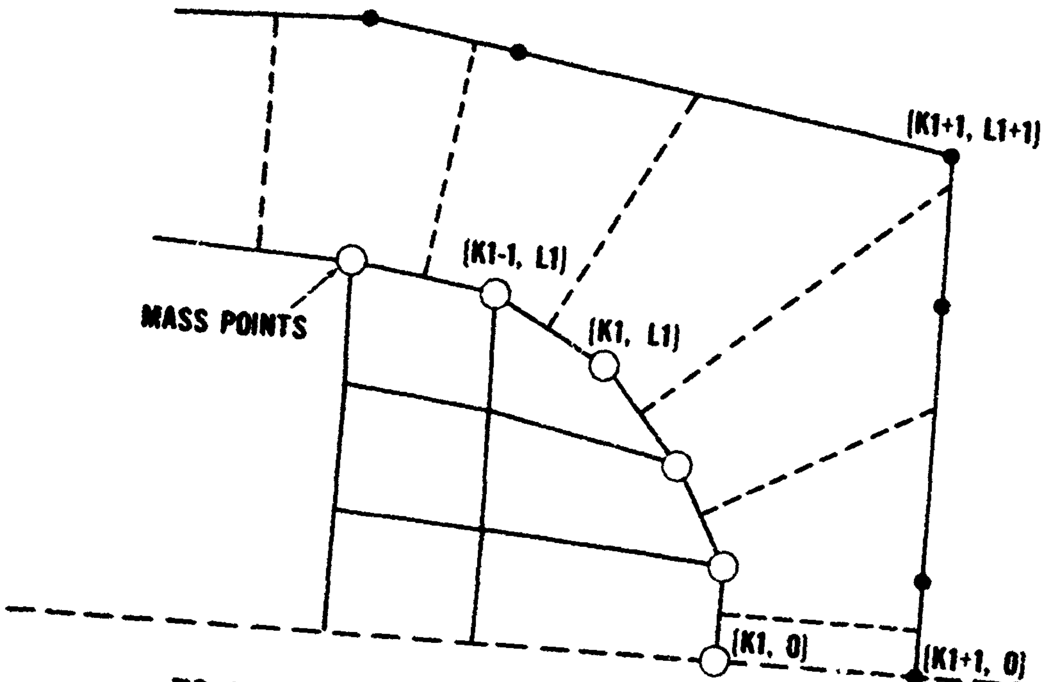

FIG. 3 GRID POINT LAYOUT FOR 105 MM PROJECTILE BASE

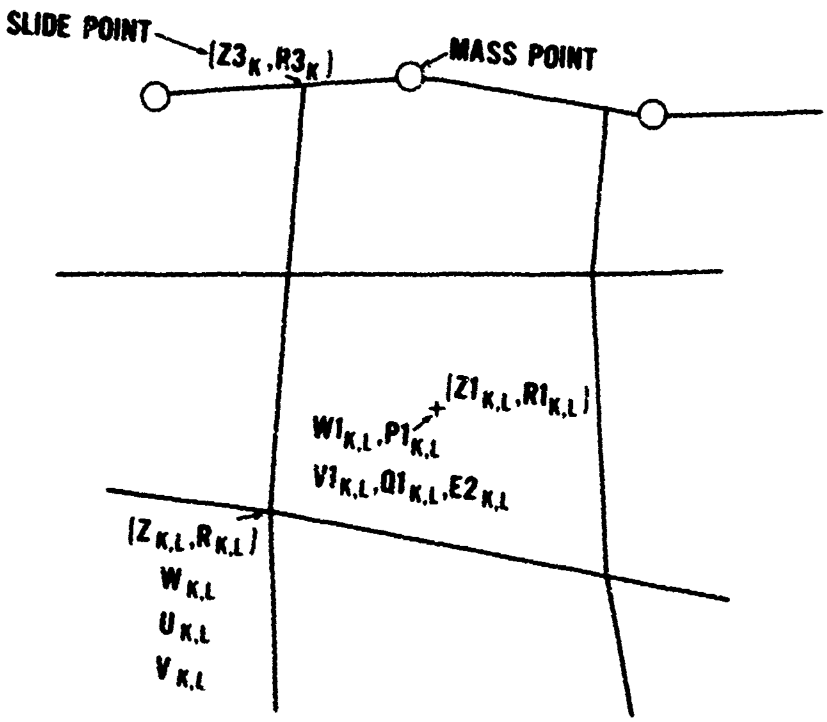

FIG. 4 SLIDE POINTS AND VARIABLE CENTERING

it protrudes into the HE cavity. If the fuze does not protrude into the cavity, $K4=0$.

An initial density $R2_{K,L}$, either the inert material density or the solid HE density, is stored for each cell.

The grid point locations are used to calculate the values of the scaled masses $W1_{K,L}$ associated with the cells. Fig.5 shows how the volumes are calculated by decomposition into triangles. For example, to get the volume associated with a cell, using the notation in Fig.4, let the vertices of one triangle be

$$X1 = Z_{K,L} \qquad X2 = Z_{K+1,L} \qquad X3 = Z_{K,L+1}$$
$$Y1 = R_{K,L} \qquad Y2 = R_{K+1,L} \qquad Y3 = R_{K,L+1} \; .$$

Then calculate the scaled volume (volume/2π) swept out by rotating the triangle about the axis from

$$\left.\begin{aligned} A &= [(X1\cdot Y2 - X2\cdot Y1) + (X2\cdot Y3 - X3\cdot Y2) + (X3\cdot Y1 - X1\cdot Y3)]/2, \\ V3 &= |A|\cdot(Y1 + Y2 + Y3)/3 \; . \end{aligned}\right\} \qquad (1)$$

A similar calculation is made for the adjoining triangle in the cell. Then

$$W1_{K,L} = (V3 + V4)\cdot R2_{K,L} \; , \qquad (2)$$

where $V3$ and $V4$ are the two scaled volumes and $R2_{K,L}$ is the initial density.

The scaled masses $W_{K,L}$ for the interior grid points and the metal mass points are calculated in a similar way. The subdivision of the various areas into triangles is shown in Fig.5. Both the scaled masses of the metal mass points and those associated with the interior grid points are denoted by $W_{K,L}$. The scaled masses of the HE associated with the gas grid points on the boundary are called $W3_{K,L}$. The quantities $W1_{K,L}$, $W_{K,L}$, $W3_{K,L}$ are calculated once, at the beginning, and then used throughout the calculation. The quantities $W3_{K,L}$ are not used in calculating the metal mass point motions because the boundary point pressures are obtained by extrapolation and interpolation. They are, however, used in the slide routine and in the energy check made at the end of each computation cycle.

The velocity components, relative specific volumes, and energies must be specified for the initial time. Usually one sets $U^{\circ}_{K,L}=0$, $V^{\circ}_{K,L}=0$, $V1^{\circ}_{K,L}=1$. Also $EZ^{\circ}_{K,L}=0$ for $K=1$ to $K4$ (if $K4\neq 0$), and $EZ^{\circ}_{K,L}=\tilde{E1}\,\rho_0$, where $\tilde{E1}$ is the energy released per gram of HE, for $K > K4$.

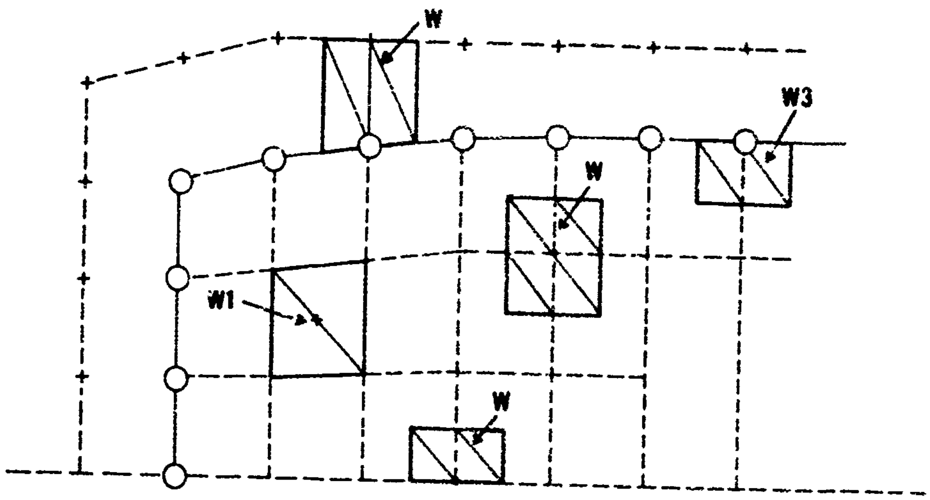

FIG. 5 CALCULATION OF MASSES BY DECOMPOSITION INTO TRIANGLES

The detonation can be started on the left boundary of the HE, on the line $K = K4+1$. The initial time is taken as

$$T = (Z1_{K4+1,0} - Z_{K4+1,0})/D$$

the time for the detonation front to traverse a half cell. There is also provision for starting the detonation at the point $(Z_{K4+1}, 0)$.

B. Flow Equations

The equations governing the flow can be written

Velocity

$$dZ/dT = U \quad , \quad dR/dT = V \tag{3}$$

Continuity

$$\rho AR = W \quad , \quad \rho 1 \cdot A1 \cdot R1 = W1 \tag{4}$$

Artificial viscosity

$$Q1 = C3^2 \rho_o (A1/V1)\left[(1/V1)\, dV1/dT\right]^2 \tag{5}$$

Equation of state of detonation products

$$\tilde{P}1 = P1(E2, V1) \cdot F \tag{6}$$

Energy

$$P2 = \tilde{P}1 + Q1 \tag{7}$$

$$dE2/dT + P2 \cdot dV1/dT = 0 \tag{8}$$

Acceleration

Interior points

$$dU/dT = -(1/\rho)\, \partial P2/\partial Z, \quad dV/dT = -(1/\rho)\, \partial P2/\partial R \tag{9}$$

Metal mass points

$$2\pi W\, dU/dT = \tilde{A}_Z P5, \quad 2\pi W\, dV/dT = \tilde{A}_R P5 \tag{10}$$

In (5), $C3$ is a constant and a quadratic artificial viscosity has been used. Equation (6) contains the burn fraction F, the fraction of the cell traversed by the detonation front.

Provision is made for detonation product equations of state of the form

$$P1 = C4 \cdot E2 + C5. \tag{11}$$

Here, $C4$ and $C5$ are functions of the relative specific volume $V1$. The sound speed is needed in the time step calculation. Since

$$C2 = (\partial P1/\partial \rho)_S = -(V1^2/\rho_o)(\partial P1/\partial V1)_S$$

and

$$(\partial E2/\partial V1)_S = -P1 ,$$

where $C2$ is the sound speed squared and S is the entropy, we have from (11)

$$C2 = -(V1^2/\beta)[dC5/dV1 - P1 \cdot C4 + (dC4/dV1) \cdot E2]. \tag{12}$$

Calculations are presently being made with the JWL equation of state[*], which has the form (11), with

$$\left.\begin{aligned} C4 &= D2/V1 , \\ C5 &= D3(1-C4/F1)\exp(-F1/V1) + D4(1-C4/F2)\exp(-F2 \cdot V1), \end{aligned}\right\} \tag{13}$$

where D2, D3, D4, F1, and F2 are constants.

Let K and L be Lagrangian coordinates, or grid point labels, initially in the Z and R directions, respectively. Then all the flow variables, including Z and R, are functions of K, L, and T. Now

$$\left.\begin{aligned} \partial P2/\partial K &= (\partial P2/\partial R)\,\partial R/\partial K + (\partial P2/\partial Z)\,\partial Z/\partial K , \\ \partial P2/\partial L &= (\partial P2/\partial R)\,\partial R/\partial L + (\partial P2/\partial Z)\,\partial Z/\partial L , \end{aligned}\right\} \tag{14}$$

from which,

$$\left.\begin{aligned} \partial P2/\partial R &= [(\partial P2/\partial K)\,\partial Z/\partial L - (\partial P2/\partial L)\,\partial Z/\partial K]\,/\,\partial(R,Z)/\partial(K,L) , \\ \partial P2/\partial Z &= [(\partial P2/\partial L)\,\partial R/\partial K - (\partial P2/\partial K)\,\partial R/\partial L]\,/\,\partial(R,Z)/\partial(K,L) . \end{aligned}\right\} \tag{15}$$

Combining (4), and (9), and using the fact that

$$A = -\,\partial(R,Z)/\partial(K,L) ,$$

leads to

$$\left.\begin{aligned} dU/dT &= (R/W)[(\partial P2/\partial L)\,\partial R/\partial K - (\partial P2/\partial K)\,\partial R/\partial L] , \\ dV/dT &= (R/W)[(\partial P2/\partial K)\,\partial Z/\partial L - (\partial P2/\partial L)\,\partial Z/\partial K] . \end{aligned}\right\} \tag{16}$$

The equations in (16) are used to calculate the gas grid point accelerations. The motion of a metal mass point on the boundary is found from (10), where $2\pi W$ is the mass, $\tilde{A}_Z$ and $\tilde{A}_R$ are projected areas in the Z and R directions, and P5 is the pressure associated with the mass point. The projected areas $\tilde{A}_Z$ and $\tilde{A}_R$ are found by working with lines connecting the mass points.

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[*] Metal Acceleration of Chemical Explosives. J. W. Kury, H. C. Hornig, E. L. Lee, J. L. McDonnel, D. L. Ornellas, M. Finger, F. M. Strange, and M. L. Wilkins. Proc. Symp. Detonation, 4th, Office of Naval Research, Rept. ACR-126, pp. 3-13, U. S. Govt. Printing Office, Washington, D.C., 1965.

The motion of a slide point is shown in Fig.6. Suppose the slide point to be moved, $Z3_K, R3_K$ is located on the line joining the mass points labeled 1 and 2 in Fig.6. The slide point is first moved along the line joining the old grid points 1 and 2, to $Z4_K, R4_K$. The point $Z4_K, R4_K$ may extend beyond the point 1 or 2. This is done just before the new grid point velocities are calculated. At the beginning of the following cycle, after the interior grid points and the mass points have been moved to their new locations, the new location of the slide point $Z3_K, R3_K$ is found by intersecting the line joining $Z4_K, R4_K$ and $Z^N_{K,LL-1}, R^N_{K,LL-1}$ with the new boundary.

C. Main Routine - Difference Equations

Figure 7 is an outline of a computation cycle. At the beginning, the cycle number N is advanced by setting $N=N+1$. Relative to this new cycle number we have the previously calculated quantities (see Fig.7)

$$T1 = T^N - T^{N-1} \quad , \quad T2 = T^{N-1/2} - T^{N-3/2} \quad , \tag{17}$$

$$Z^{N-1}_{K,L}\ ,\ R^{N-1}_{K,L}\ ,\ Z4^N_K\ ,\ R4^N_K\ ,\ V1^{N-1}_{K,L}\ ,\ Q1^{N-3/2}_{K,L}\ ,\ P2^{N-1}_{K,L}\ ,$$

$$E2^{N-1}_{K,L}\ ,\ C2^{N-1}_{K,L}\ ,\ A1^{N-1}_{K,L}\ ,\ U^{N-1/2}\ ,\ V^{N-1/2}\ .$$

Following the order in Fig.7 put

$$T^N = T^{N-1} + T1\ .$$

<u>Limited Computation</u>

Assume that the detonation starts on the surface $K=K4+1$ or at the point $K=K4+1, L=0$. Let $K3$ be the maximum K for which the cell center variables $P1, V1, Q1, E2, C2$ will be calculated and let

$$Z = Z^0_{K4+1,0}\ .$$

Set

$$\left.\begin{aligned} \widetilde{K3} &= 5 + \text{the maximum } K \text{ for which } D\cdot T - Z_{K,0} + Z > 0 \\ K3 &= \min\left\{\widetilde{K3}\ ,\ K1-1\right\}\ . \end{aligned}\right\} \tag{18}$$

Here D is the detonation velocity. The additional five K lines in (18) are needed to establish a detonation wave peak pressure close to the Chapman-Jouguet (CJ) pressure. This works because the artificial viscosity term causes the solid ahead of the detonation front to be artificially compressed.

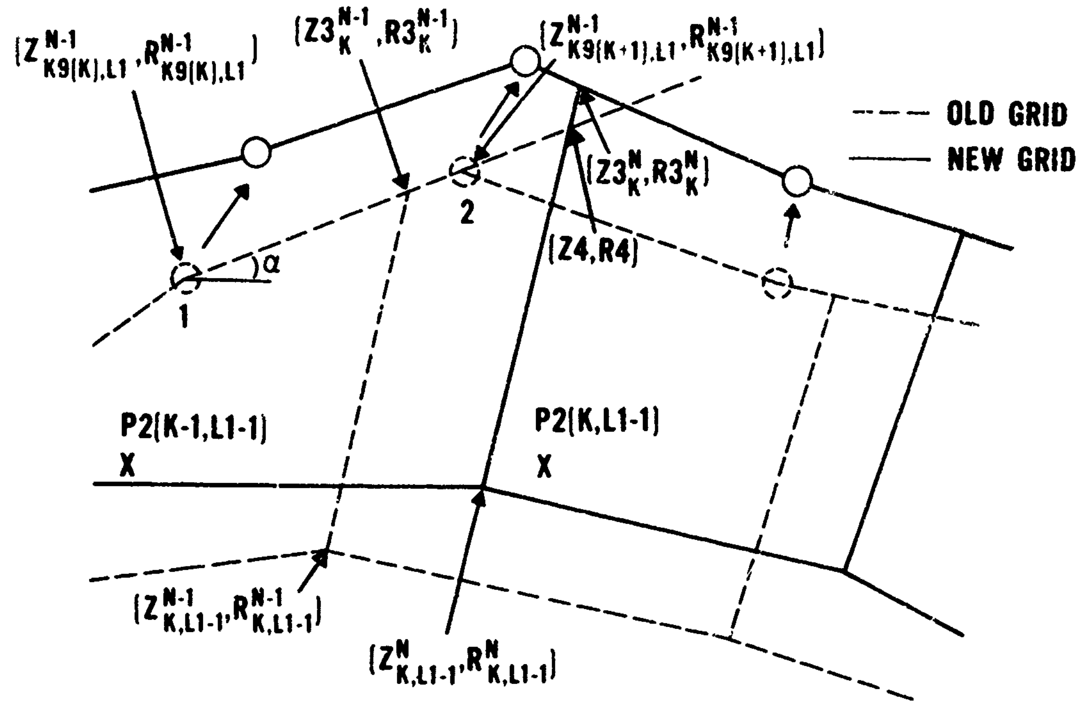

FIG. 6 SLIDE POINT MOTION

→ ADVANCE CYCLE NUMBER N AND TIME T.

CALCULATE NEW VALUES IN THE ORDER LISTED:

1. MAXIMUM K FOR LIMITED COMPUTATION IF THE DETONATION FRONT HAS NOT REACHED K = K1.
2. POSITIONS OF INTERIOR GRID POINTS, AXIS POINTS, AND METAL MASS POINTS $Z^N_{K,L}$, $R^N_{K,L}$.
3. POSITIONS OF SLIDE POINTS $Z3^N_K$, $R3^N_K$.
4. BURN FRACTION F_K.
5. AREAS $A1^N_{K,L}$, RELATIVE SPECIFIC VOLUMES $V1^N_{K,L}$, ARTIFICIAL VISCOSITIES $Q1^{N-1/2}_{K,L}$, PRESSURES $P1^N_{K,L}$, ENERGIES $E2^N_{K,L}$, SOUND SPEEDS, AND CELL TIME STEPS $T3^N_{K,L}$.
6. TIME STEPS T1 AND T2.
7. MOTION OF SLIDE POINTS TO $Z4^N_K$, $R4^N_K$.
8. VELOCITIES OF INTERIOR GRID POINTS, AXIS POINTS, AND METAL MASS POINTS $U^{N+1/2}_{K,L}$, $V^{N+1/2}_{K,L}$.

AT SPECIFIED TIMES, PRINT OUT RESULTS AND MAKE FRAGMENT PREDICTION CALCULATIONS.

MAKE ENERGY CHECK.

← RETURN TO START.

FIG. 7 FLUID DYNAMICS–COMPUTATION CYCLE

New Positions

The new positions of the interior grid points, axis points, and metal mass points are calculated from (3). In difference form

$$\left.\begin{aligned} Z^{N}_{K,L} &= Z^{N-1}_{K,L} + T1 \cdot U^{N-1/2}_{K,L} \;, \\ R^{N}_{K,L} &= R^{N-1}_{K,L} + T1 \cdot V^{N-1/2}_{K,L} \;. \end{aligned}\right\} \qquad (19)$$

After all the Z, R points are moved, the new slide points $Z3^{N}_{K}, R3^{N}_{K}$ are found by intersecting the lines joining $Z4^{N}_{K}, R4^{N}_{K}$ (calculated during the previous cycle) and $Z^{N}_{K,L1-1}, R^{N}_{K,L1-1}$ (see Fig.6) with the new boundary. To do this the appropriate segment of the boundary must be found for each slide point. Suppose the equation of the line through $Z4^{N}_{K}, R4^{N}_{K}$ and $Z^{N}_{K,L1-1}, R^{N}_{K,L1-1}$ is

$$d = a\tilde{Z} + b\tilde{R} + c = 0. \qquad (20)$$

If the coordinates of a point not on the line are inserted for $\tilde{Z}$ and $\tilde{R}$ in (18), then the sign of d will depend on the side of the line the point is on. The proper boundary segment can thus be found by inserting the mass point coordinates $Z^{N}_{J,L1}, R^{N}_{J,L1}$, successively, into (18), starting with $J=1$, and testing for a sign change. Since $Z4_{K} - Z_{K,L1-1}$ may be zero, it is convenient to put

$$S8_{K} = -(Z4_{K} - Z_{K,L1-1})/(R4_{K} - R_{K,L1-1}) \;, \qquad (21)$$

$$d = (\tilde{Z} - Z_{K,L1-1}) + S8_{K}(\tilde{R} - R_{K,L1-1}) \;, \qquad (22)$$

and substitute, successively $Z_{J,L1}$ and $R_{J,L1}$, for $\tilde{Z}$ and $\tilde{R}$. After the value of J for the left endpoint of the proper line segment is found, $Z3_{K}$ and $R3_{K}$ are obtained from the intersection of the two lines, i.e., by solving the system

$$S7 = (R_{J+1,L1} - R_{J,L1})/(Z_{J+1,L1} - Z_{J,L1}) \;, \qquad (23)$$

$$\begin{aligned} (\tilde{R} - R_{J+1,L1}) - S7 \cdot (\tilde{Z} - Z_{J+1,L1}) &= 0 \;, \\ (\tilde{Z} - Z_{K,L1-1}) + S8_{K}(\tilde{R} - R_{K,L1-1}) &= 0 \;. \end{aligned} \qquad (24)$$

The variable $K9_{K}$ is now set equal to J, to identify the first mass point to the left of the slide point $Z3_{K}, R3_{K}$.

Burn Fraction

The term burn fraction, denoted here by F, refers to the fraction of an HE cell considered to be converted to detonation products. If the detonation front is taken to be perpendicular to the axis, F is a function of K only. Then, with D the detonation velocity, we take (see Ref.2)

$$\left.\begin{aligned}\tilde{F}_K &= \max\left\{(D\cdot T - Z_{K,0} + Z)/(Z_{K+1,L1} - Z_{K,0})\ ,\ (1 - V1_{K,0})/(1 - V1_{CJ})\right\}\\ F_K &= \min\left\{1, \tilde{F}_K\right\}.\end{aligned}\right\}\quad (25)$$

Here $Z = Z_{K4+1,0}$ at $T=0$, the initiation plane, and $V1_{CJ}$ is the relative specific volume at the CJ state, a constant for the explosive.

To initiate at a point let the burn fraction be the ratio of the time the detonation front has been in the cell to the time for the detonation front to traverse the cell. Let Z, R be the coordinates of the initiation point at $T=0$ and let

$$G_{K,L} = \left[(R_{K,L} - R)^2 + (Z_{K,L} - Z)^2\right]^{1/2}. \qquad (26)$$

Then take

$$\left.\begin{aligned}\tilde{F}_{K,L} &= \max\left\{(D\cdot T - G_{K,L})/(G_{K+1,L+1} - G_{K,L})\ ,\ (1 - V1_{K,L})/(1 - V1_{CJ}),\right.\\ F_{K,L} &= \min\left\{1, \tilde{F}_{K,L}\right\}.\end{aligned}\right\}\quad (27)$$

At the present time there is provision in the program for plane detonation only ($F = F_K$). Initiation at one or more points can be done by making appropriate changes in the burn fraction and equation of state routines.

<u>Area, Specific Volume, Pressure, Energy, and Sound Speed</u>

The area, relative specific volume, pressure, energy, sound speed and cell time step are all calculated for a single cell before moving on to the next cell. To get the area $A1_{K,L}$ the cell is divided into two triangles and the triangle routine (1) is used. Note that for the uppermost cells (see Fig.4) the corners are $(Z_{K,L1-1}, R_{K,L1-1})$, $(Z_{K+1,L1-1}, R_{K+1,L1-1})$, $(Z3_{K+1}, R3_{K+1})$, $(Z3_K, R3_K)$. Let $V3$ and $V4$ be the scaled volumes of the two triangles, obtained with (1). Then

$$V1_{K,L} = (V3 + V4)\cdot R2_{K,L}/W1_{K,L}. \qquad (28)$$

The artificial viscosity (see (5)) is now calculated from

$$Q1_{K,L}^{N-1/2} = C3^2 \cdot R2_{K,L} \cdot V9^2 \cdot (A1_{K,L}^N + A1_{K,L}^{N-1})/(V1_{K,L}^N + V1_{K,L}^{N-1}), \qquad (29)$$

where

$$V9 = \left[(V1_{K,L}^N - V1_{K,L}^{N-1})/T1\right]\cdot 2/(V1_{K,L}^N + V1_{K,L}^{N-1}). \qquad (30)$$

If $V9 > 0$, then $Q1_{K,L}^{N-1/2} = 0$.

Arrays in storage are for a single time step only. The values of $A1_{K,L}^{N-1}$, $V1_{K,L}^{N-1}$, $P1_{K,L}^{N-1}$, and $E2_{K,L}^{N-1}$ are stored, temporarily, as unsubscripted quantities, before the new values are found, for use in (29), (30), and in the pressure, energy and cell time step calculations.

The pressure $P1$ and the energy $E2$ are found by solving (6)-(8) simultaneously. When the JWL equation is used, $C4$ and $C5$ are calculated from (13), using $V1_{K,L}^{N}$. The following are then solved by iteration, starting with the first approximation

$$P1_{K,L}^{N} = C4 \; E2_{K,L}^{N} + C5, \qquad (31)$$

$$E2_{K,L}^{N} = E2_{K,L}^{N-1} - \left[\left(P1_{K,L}^{N} + P1_{K,L}^{N-1}\right)/2 + Q1_{K,L}^{N-1/2}\right]\left(V1_{K,L}^{N} - V1_{K,L}^{N-1}\right). \qquad (32)$$

The new values of $P1_{K,L}^{N}$, $E2_{K,L}^{N}$, $V1_{K,L}^{N}$ with derivatives of $C4$ and $C5$ from (13), are inserted into (12) to get the square of the sound speed $C2_{K,L}^{N}$.

Time Step

The time step is determined by numerical stability criteria, with the form taken directly from the HEMP code[2]. This is a composite of two criteria, one for the shock regions, the other requiring that a signal pass only part way through a cell in one time step. The minimum of the time steps found for the individual cells is taken as the new time step.

To find the cell time step we first get the smallest diagonal from

$$\left.\begin{aligned} S3 &= [(Z^N_{K+1,L+1} - Z^N_{K,L})^2 + (R_{K+1,L+1} - R_{K,L})^2], \\ S4 &= [(Z^N_{K,L+1} - Z^N_{K+1,L})^2 + (R_{K,L+1} - R_{K+1,L})^2], \end{aligned}\right\} \quad (33)$$

$$S5 = [\min\ \{S3, S4\}]^{1/2}. \quad (34)$$

For the uppermost cells, where $L = L1 - 1$, $Z3_K$ and $R3_K$ are used in place of $R_{K,L1}$ and $Z_{K,L1}$. Then the cell time step $T3_{K,L}$ is given by

$$\left.\begin{aligned} T3_{K,L} &= S5/(3(CZ^N_{K,L} + B^2)^{1/2}), \\ \text{where}\quad B &= 0 \ \text{ if } V9 > 0, \\ B &= 2 \cdot C3 \cdot S5 \cdot V9 \ \text{ if } V9 \le 0 \end{aligned}\right\} \quad (35)$$

The quantities $C3$ and $V9 (= \dot{V1}/V1)$ appear in (29).

The new time step is then found from

$$T1^{N+1} = \min\ \{\min\ T3_{K,L},\ T1^N \cdot E8\} \quad (36)$$

where $E8$ is a constant (1.1 is now being used, i.e., the time step is not allowed to jump more than 10% in a single time step). Also set

$$T2^{N+1/2} = (T1^{N+1} + T1^N)/2. \quad (37)$$

The time step $T1^{N+1}$ will be used in the next computation cycle, but $T2^{N+1/2}$ will be used in this cycle, to get the velocities.

Slide Point Motion

To move the slide point along the line joining points 1 and 2 in Fig.6, let $G9$ be the velocity along the line. Then

$$dG9/dT = -(1/\rho)[\partial P2/\partial Z \cdot \cos\ \alpha + \partial P2/\partial R \cdot \sin\ \alpha] \quad (38)$$

$$dU7/dT = dG9/dT \cos\alpha \tag{39}$$

$$dV7/dT = dG9/dT \sin\alpha \tag{40}$$

$$dZ/dT = U7 \ , \ dR/dT = V7 \ ,$$

where α is the angle with the Z axis shown in Fig.6 and $U7, V7$ are the velocity components. To find $\partial P2/\partial Z$ and $\partial P2/\partial R$ in (38), we can use (15). Since the line $L = L1$ is being held fixed, $\partial P2/\partial L = 0$. Also, since there are only two quarter cells associated with the point $Z3_K, R3_K$, equation (4) must be replaced by

$$\rho A R = 2 W3 . \tag{41}$$

Then, using (15), (38), and (41),

$$(dG9/dT)_{K,L1} = [R3_K/(2 \cdot W3_{K,L1})] (\partial P2/\partial K)_{K,L1} [(\partial Z/\partial L)_{K,L1} \sin\alpha - (\partial R/\partial L)_{K,L1} \cos\alpha] \tag{42}$$

where

$$(\partial P2/\partial K)_{K,L1} = P2^N_{K,L1-1} - P2^N_{K-1,L1-1} \tag{43}$$

$$(\partial Z/\partial L)_{K,L1} = Z3^N_K - Z^N_{K,L1-1} \tag{44}$$

$$(\partial R/\partial L)_{K,L1} = R3^N_K - R^N_{K,L1-1} \tag{45}$$

$$\cos\alpha = (Z_2 - Z_1)/[(Z_2 - Z_1)^2 + (R_2 - R_1)^2]^{1/2} , \tag{46}$$

$$\sin\alpha = (R_2 - R_1)/[(Z_2 - Z_1)^2 + (R_2 - R_1)^2]^{1/2} . \tag{47}$$

The subscripts 1 and 2 in (46) and (47) refer to the labeled mass point locations in Fig.6. We then get $U7_K, V7_K, Z4_K$ and $R4_K$, using (39) and (40) with

$$\left. \begin{aligned} U7^{N+1/2}_K &= U^{N-1/2}_{K,L1-1} + (dG9/dT)_{K,L1} \cos\alpha \cdot T2 \\ V7^{N+1/2}_K &= V^{N-1/2}_{K,L1-1} + (dG9/dT)_{K,L1} \sin\alpha \cdot T2 \end{aligned} \right\} \tag{48}$$

$$\left. \begin{aligned} Z4^{N+1}_K &= Z3^N_{K,L1} + U7^{N+1/2}_K \cdot T1 \\ R4^{N+1}_K &= R3^N_{K,L1} + V7^{N+1/2}_K \cdot T1 \end{aligned} \right\} \tag{49}$$

Note that here, as in the HEMP code , the old velocities at the point $(K, L1-1)$ are used to calculate $U7_K$ and $V7_K$ from (39) and (40).

Velocity-Interior Grid Points

New velocities of the interior grid points not on the axis are found from a difference form of (16), viz.,

$$U_{K,L}^{N+1/2} = U_{K,L}^{N-1/2} + T2 \cdot (R_{K,L}^{N}/W_{K,L})\left[(\partial P2/\partial L)_{K,L}(\partial R/\partial K)_{K,L} - (\partial P2/\partial K)_{K,L}(\partial R/\partial L)_{K,L}\right], \quad (50)$$

$$V_{K,L}^{N+1/2} = V_{K,L}^{N-1/2} + T2 \cdot (R_{K,L}^{N}/W_{K,L})\left[(\partial P2/\partial K)_{K,L}(\partial Z/\partial L)_{K,L} - (\partial P2/\partial L)_{K,L}(\partial Z/\partial K)_{K,L}\right], \quad (51)$$

where

$$(\partial P2/\partial K)_{K,L} = (P2_{K,L}^{N} + P2_{K,L-1}^{N} - P2_{K-1,L}^{N} - P2_{K-1,L-1}^{N})/2 , \quad (52)$$

$$(\partial P2/\partial L)_{K,L} = (P2_{K-1,L}^{N} + P2_{K,L}^{N} - P2_{K-1,L-1}^{N} - P2_{K-1,L}^{N})/2 , \quad (53)$$

$$\begin{aligned} (\partial R/\partial K)_{K,L} &= (R_{K+1,L}^{N} - R_{K-1,L}^{N})/2 , \\ (\partial R/\partial L)_{K,L} &= (R_{K,L+1}^{N} - R_{K,L-1}^{N})/2 , \\ (\partial Z/\partial K)_{K,L} &= (Z_{K+1,L}^{N} - Z_{K-1,L}^{N})/2 , \\ (\partial Z/\partial L)_{K,L} &= (Z_{K,L+1}^{N} - Z_{K,L-1})/2 . \end{aligned} \quad (54)$$

Velocity-Interior Axis Points

For the interior axis points (9) will be used directly. Note first that on the axis $dV/dT=0$, so that $\partial P2/\partial R=0$, and from (14)

$$\partial P2/\partial Z = (\partial P2/\partial L)/(\partial Z/\partial L) \text{ (axis points)}. \quad (55)$$

The density ρ needed in (9) is given by

$$\rho = W_{K,0}/B1 , \quad (56)$$

where $B1$ is the sum of the scaled volumes of the two quarter cells at the point $(K,0)$. To get these volumes the centers $Z1_{K,0}$, $R1_{K,0}$ of the adjoining cells are found, first, by averaging the Z and R coordinates of the corners. Then the scaled volumes of the two quarter cells are found by subdivision into triangles (see Fig.8) with the same quarter cell routines that are used in the initialization. The velocity components are now

$$U_{K,0}^{N+1/2} = U_{K,0}^{N-1/2} - T2\,(B1/W_{K,0}) \cdot 2\,(P2_{K,0}^{N} - P2_{K-1,0}^{N})/(Z_{K+1,0} - Z_{K-1,0}) , \quad (57)$$

$$V_{K,0}^{N+1/2} = 0. \quad (58)$$

Velocity-Metal Mass Points

The equations in (10) are used to calculate the velocities of the metal mass points. The notation is shown in Fig.8. The pressures at the slide points, denoted by $P3_J$, are found first, by extrapolation with

$$\left.\begin{aligned} P4 &= (P2_{J,L1-1} + P2_{J-1,L1-1})/2 \\ P3 &= (P2_{J,L1-2} + P2_{J-1,L1-2})/2 \\ P3_J &= (3P4 - P3)/2 \end{aligned}\right\} \quad (59)$$

The subscripted variable $P3_J$ is different from $P3$, a distinction allowed in BASIC programming.

The pressure at a mass point is found by locating the nearest slide points on both sides and interpolating with respect to distance from the slide points. The adjacent slide points are located by essentially the same method used to find $Z3_K$ and $R3_K$ (Eq.(20)). The equation for the line through a slide point can be written (Eq.(21))

$$(\tilde{Z} - Z_{J,L1-1}) + S8_J(\tilde{R} - R_{J,L1-1}) = 0. \quad (60)$$

Here $S8_J$, the negative reciprocal of the slope of the slide line, was previously calculated with (21) and stored. Now, starting with $J=1$, evaluate

$$G_J = (Z_{K,L1} - Z_{J,L1-1}) + S8_J(R_{K,L1} - R_{J,L1-1}) \quad (61)$$

for successive values of J, until the sign of G_{J+1} is different from the sign of G_J. Then for the values of J and $J+1$ where the signs differ, compute

$$\left.\begin{aligned} D7 &= [(Z_{K,L1} - Z3_J)^2 + (R_{K,L1} - R3_J)^2]^{1/2} \\ D8 &= [(Z_{K,L1} - Z3_{J+1})^2 + (R_{K,L1} - R3_{J+1})^2]^{1/2} \end{aligned}\right\} \quad (62)$$

and $P5$ the pressure at the mass point by

$$P5 = P3_J + D7 \cdot (P3_{J+1} - P3_J)/(D7 + D8). \quad (63)$$

Assume that the mass associated with the mass point $Z_{K,L1}, R_{K,L1}$ is uniformly distributed over a band whose cross section consists of the pieces between the point and the midpoints of the line segments joining the point and the adjacent points (Fig.8). Then, in (10), take the projected areas

$$\left.\begin{aligned} \tilde{A}_Z &= (\pi/4)[(R_{K-1,L1} + R_{K,L1})^2 - (R_{K+1,L1} + R_{K,L1})^2], \\ \tilde{A}_R &= (\pi/4)[(3R_{K,L1} + R_{K-1,L1})(Z_{K,L1} - Z_{K-1,L1}) + (3R_{K,L1} + R_{K-1,L1})(Z_{K+1,L1} - Z_{K,L1}). \end{aligned}\right\} \quad (64)$$

Now, using (10),

$$\left.\begin{aligned} U_{K,L1}^{N+1/2} &= U_{K,L1}^{N-1/2} + T2 \cdot A_Z \cdot P5/(8W_{K,L1}), \\ V_{K,L1}^{N+1/2} &= V_{K,L1}^{N-1/2} + T2 \cdot A_R \cdot P5/(8W_{K,L}), \end{aligned}\right\} \quad (65)$$

where

$$A_z = (4/\pi)\tilde{A}_z \quad , \quad A_R = (4/\pi)\tilde{A}_R \quad .$$

Similar formulas, with appropriate subscripts, are used to get the velocities of the metal mass points located on the lines $K = 1$ and $K = K1$.

Energy Check

The total energy in the system is summed at the end of every cycle. Denote the total internal energy by IE and the total kinetic energy by KE. The total energy E_T is found from

$$E_T = IE + KE \tag{66}$$

where

$$IE = 2\pi \sum_{K=1}^{K1-1} \sum_{L=0}^{L1-1} W1_{K,L} \cdot E2_{K,L} / R2_{K,L} \quad , \tag{67}$$

$$KE = \pi \sum_{K=1}^{K1} \cdot \sum_{L=0}^{L1} W_{K,L} \left(U_{K,L}^2 + V_{K,L}^2 \right)$$

$$+ \pi \sum_{L=0}^{L1} \left\{ W3_{1,L} \left(U_{1,L}^2 + V_{1,L}^2 \right) + W3_{K1,L} \left(U_{K1,L}^2 + V_{K1,L}^2 \right) \right\}$$

$$+ \pi \sum_{K=2}^{K1-1} W3_{K,L1} \left(U7_K^2 + V7_K^2 \right) . \tag{68}$$

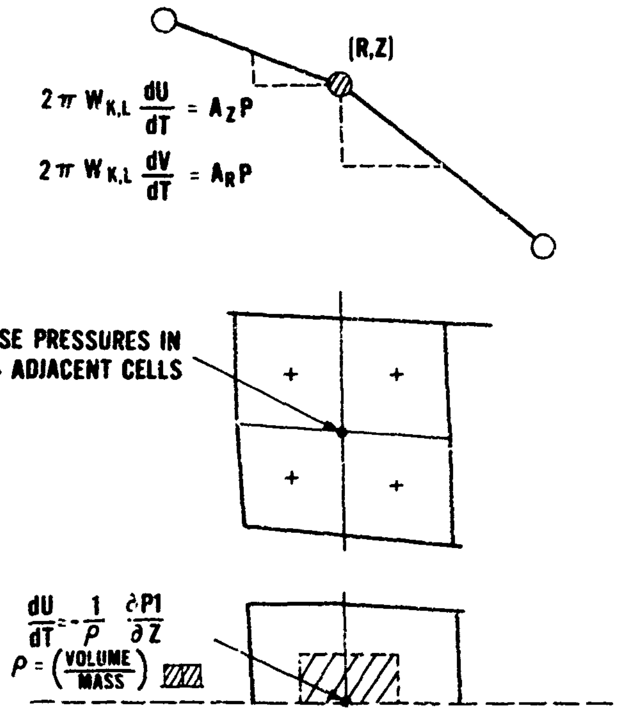

FIG. 8 VELOCITY CALCULATIONS

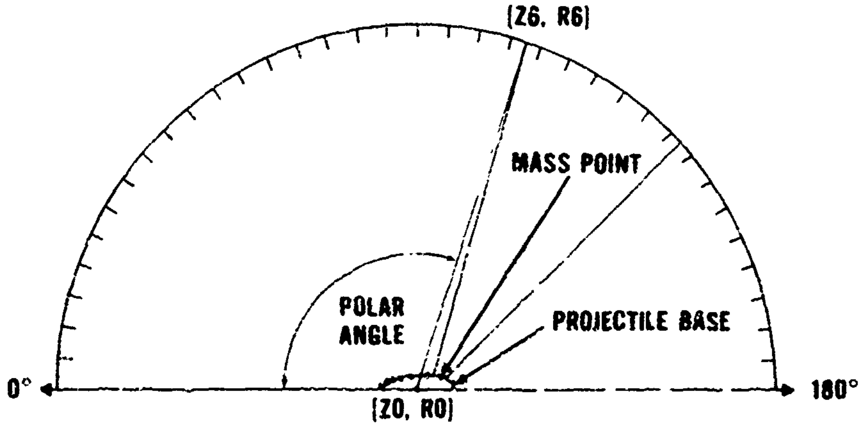

FIG. 9 WEAPON POSITION AND POLAR ANGLE

III COMPUTATION OF ARENA DATA

Suppose that the weapon is located in the center of an arena of radius D1 and center at ZO,RO in the coordinate system used for the fluid dynamic computation. Put the weapon nose and the zero polar angle at the left, as in Fig.9, and divide surrounding space into 5 degree polar zones, measured from ZO,RO. The total weight, total number, average velocity, and weight distribution of fragments in each of the polar zones are needed for lethal area studies.

The total weights and average velocities of the fragments in the various polar zones are obtained from the fluid dynamics computation. Assume that at a specified time, say the time for the center of the weapon to expand to twice its initial radius, the casing has broken into fragments and burst, acceleration of the fragments has ceased, and the directions of fragment motion are constant. In the cases for which fluid dynamic computations were made, the fragment directions were established early, and then changed very little with time. The velocities increased slowly with increasing radius after case expansions to 1.5 or 2 radii. Hence, the velocities could vary by a few percent depending upon the time chosen. The results of the fluid dynamics computations for the first cycle after the specified time are used.

The metal mass points are numbered in order starting with 1 at K=1, L=0 and ending with K1+2L1 at K=K1, L=0. Let MS be the mass point number, and let Z_{MS}, R_{MS}, U_{MS}, and V_{MS} be the corresponding coordinates and velocity components, respectively, calculated in the fluid dynamics section of the program. The midpoints of the line segments joining the mass points are then

$$Z_{MS+1/2} = (Z_{MS} + Z_{MS+1})/2 \ , \quad R_{MS+1/2} = (R_{MS} + R_{MS+1})/2 \qquad (69)$$

Also, let β_{MS} be the fragment direction angle for the mass point MS i.e.,

$$\beta_{MS} = \arctan\,(V_{MS}/U_{MS}) \ , \qquad (70)$$

and, for the fragment directions from the midpoints, take

$$\beta_{MS+1/2} = (\beta_{MS} + \beta_{MS+1})/2 . \qquad (71)$$

The corresponding polar angle $A9_{MS+1/2}$, the angle between the horizontal and a line drawn from the point where the fragment direction intersects the circle to the point $Z0, R0$ (see Fig.9), is obtained by solving, simultaneously

$$\left. \begin{array}{l} (Z6 - Z0)^2 + (R6 - R0)^2 = D1^2 \\ (R6 - R_{MS+1/2}) - \tan \beta_{MS+1/2} \, (Z6 - Z_{MS+1/2}) = 0 \end{array} \right\} \qquad (72)$$

for $Z6$ and $R6$, and taking

$$A9_{MS+1/2} = \arctan \left[(Z6 - Z0)/(R6 - R0) \right] . \qquad (73)$$

The scaled mass ($= W_{K,L}$ in the fluid dynamics program) associated with each mass point MS is distributed uniformly over the full and partial polar zones between the polar angles $A9_{MS-1/2}$ and $A9_{MS+1/2}$. Denote the contribution of the mass point MS to the $J2$th polar zone by $W7_{J2,MS}$. After the scaled masses of all the mass points are distributed over the appropriate polar zones, the total fragment mass and average fragment velocity in each polar zone are calculated from

$$W8_{J2} = \sum_{MS=1}^{K1+2L1} W7_{J2,MS} ,$$

total fragment mass in polar zone $J2 = 2\pi W8_{J2}$, and

average fragment velocity in polar zone $J2$

$$= \left(\sum_{MS=1}^{K1+2L1} Q3_{MS} \cdot W7_{J2,MS} \right) \Big/ W8_{J2} ,$$

where

$$Q3_{MS} = (U_{MS}^2 + V_{MS}^2)^{1/2} \qquad (76)$$

is the velocity of the mass point MS.

The numbers of fragments in various weight ranges in the individual polar zones are obtained from the directions calculated with the fluid dynamics program, together with weight distributions which are specified for each of the mass points.

To every mass point MS there is assigned a value of the parameter $\bar{M}$, called $M1_{MS}$, the average weight of fragments weighing more than one grain. It is assumed that the weight distribution of fragments from the mass point, the number of fragments per unit weight in the different weight ranges, depends only on this parameter and is completely determined once $M1_{MS}$ is specified. Let the total number of weight groups be $J9$. Specify $J9$ weights $M_1, M_2, \ldots, M_J, \ldots M_{J9}$, so that $M_1 = 1$ grain, the Jth weight group ($J < J9$) contains fragments with weights between M_J and M_{J+1}, and the last group contains all the fragments weighing more than M_{J9}. For each mass point MS read in or, preferably, calculate from a formula the weight distribution associated with $M1_{MS}$. This will consist of the quantities $N_{MS,J}$ the number of fragments of weight greater than M_J, in each of the $J9$ weight ranges, for the mass point M_S. Also read in or calculate $W2_{MS,J}$, the weight fractions of fragments weighing more than M_J, for each mass point.

Let $N7_{J6,J}$ be the number of fragments of weight greater than M_J in the $J6$th polar zone. This number is accumulated with

$$N7_{J6,J} = 2\pi \sum_{MS=1}^{K1+2L1} N_{MS,J} \cdot W7_{J6,MS} \quad , \tag{77}$$

while the weights from each mass point MS are being put into the polar zones between the polar angles $A9_{MS-1/2}$ and $A9_{MS+1/2}$. At the same time the scaled weight of fragments in each weight group, in each polar zone, is accumulated with

$$W5_{J6,J} = \sum_{MS=1}^{K1+2L1} W2_{MS,J} \cdot W7_{J6,MS} \quad . \tag{78}$$

Let $N3_{J6,J} = (N7_{J6,J} - N7_{J6,J+1})$ for $J < J9$. The average weight of fragments in the Jth weight group in the $J6$ th polar zone is then $2\pi(W5_{J6,J} - W5_{J6,J+1})/N3_{J6,J}$ for $J < J9$, and $2\pi\, W5_{J6,J9}/N7_{J6,J9}$ for $J = J9$. The total number of fragments of weight greater than one grain in the $J6$th polar zone is

$$N8_{J6} = \left(\sum_{J=1}^{J9-1} N3_{J6,J}\right) + N7_{J6,J9} \; . \tag{79}$$

The average weight of fragments weighing more than one grain, in the $J6$th polar zone is $2\pi\, W8_{J6}/N8_{J6}$ (see (74)).

The value of $\bar{M}$ which must be assigned to each mass point depends upon the casing diameter and wall thickness, the explosive composition and density, the type and treatment of the steel, and the impact angle of the detonation front. For the present work, fragmentation data from arena tests of 105 and 155 mm shells, with standard projectile steel casings and military grade Composition B explosive fillings, were used to construct a plot (Fig.10) of $\bar{M}$ vs. the parameter χ, where

$$\chi = t\, d_i^{1/3}/(1 + 2C/M)\; ,\; (\text{in.})^{4/3} \; . \tag{80}$$

Here, t is the wall thickness (in.), d_i is the inside diameter (in.), and C/M is the ratio of the explosive mass to the metal mass at the weapon section being considered. The parameter χ was proposed by

Magis[7]. The examination of the arena test data showed that when the fuze was at the nose end of the projectile, the fragmentation from the side wall close to the base end, beyond the part forming the main beam spray, was substantially finer than the fragmentation indicated by the value of χ. This may be due to the higher pressure in the section, produced by the reflection of the detonation wave at the base of the projectile. A second curve in Fig.10 was drawn for use with this section. Also, in the arena test data, the value of $\bar{m}$ for the base corner was less than one fourth the largest value of $\bar{m}$ in the sections forming the main beam spray.

For the sample calculations that were made, the values of $\bar{m}$ for the mass points on the side wall were taken from Fig.10, and the $\bar{m}$ for the mass points on the base corner and the base end were set equal to those observed in the arena test data. The values of $\bar{m}$ for the mass points on the line $\kappa = 1$ were arbitrarily set at 200 grains. No attempt was made to model the fuze.

Figure 10 was constructed with a limited amount of work involving both available arena data and fluid dynamic computations. The arena data was used to get the weight distributions (number of fragments per unit weight in the various weight ranges) in the different polar zones, while the fluid dynamics results were used to find the mass points, and the corresponding χ values, that had contributed to these polar zones. This kind of analysis is felt to be worth applying to other existing arena data for a wide range of shells, bombs, and warheads. It has the advantage that, in many cases, the weight distributions can be related to particular sections of the weapon where the value of the parameter χ (Eq. (80)), the detonation wave impact angle, and the acceleration history are known, from the fluid dynamics computation.

Some attempts were made to correlate the cylinder fragmentation results of Magis[7], and a weight distribution fitted to the Magis data[8],

[7] S.F. Magis, Naval Weapons Laboratory, Dahlgren, Virginia.

[8] H.M. Sternberg, "Fragment Weight Distributions from Naturally Fragmenting Cylinders Loaded with Various Explosives," U.S. Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland, NOLTR 73-83, 12 Oct 1973.

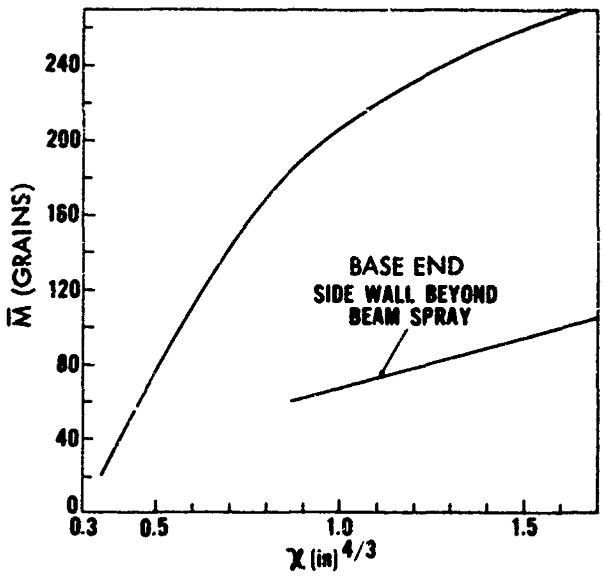

FIG. 10 $\bar{M}$ VS χ

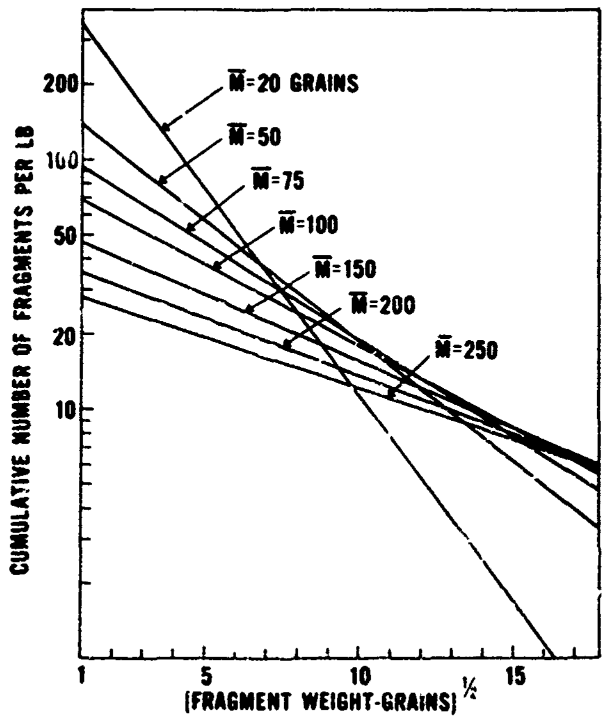

FIG. 11 THE MOTT DISTRIBUTION

with arena test data for the standard 105 and 155 mm projectiles. The agreement, overall, was poor. A likely reason for the poor agreement is that the cylinder fragments, collected in sawdust pits, were subject to secondary breakup. Another possibility follows from the fact that the cylinder data are averages of weight distributions from various sections of relatively short uncapped cylinders. These averages may not be adequate to represent weight distributions from sections of a projectile. The sample size may also be a factor. There were very few standard projectile steel experiments in the Magis work[7].

The Mott formula[9] was used for the weight distributions. This can be written

$$N(m) = (1/2\mu)\, \exp\left[-(m/\mu)^{1/2}\right] \quad , \qquad (81)$$

where m is the fragment size, μ is a parameter, and $N(m)$ is the number of fragments per unit weight, of weight greater than m. With μ in grains, $N(1)$ is the number per grain of fragments weighing more than one grain. Hence, the parameters $\bar{M}$ and μ are related by

$$\bar{M} = 2\mu\, \exp\left[(1/\mu)^{1/2}\right]. \qquad (82)$$

To calculate the Mott distribution (81), starting with $\bar{M}$, μ is needed from (82). In the computer program this was calculated with the fit

$$\left.\begin{aligned} \mu &= 20 + 0.4366(\bar{M} - 50) \quad , \qquad 20 \le \bar{M} < 50 \\ \mu &= 20 + (7/15)(\bar{M} - 50) \quad , \qquad 50 \le \bar{M} < 250 \end{aligned}\right\} \qquad (83)$$

Figure 11 contains plots of the Mott distributions $N(m)$ vs. $m^{1/2}$ for various values of the parameter $\bar{M}$. Note that by the choice of $\bar{M}$, one member of this family of lines is assigned to each mass point MS. The family forms an envelope with some interesting properties (see Ref. (8).

The input quantities $W2_{MS,J}$ the weight fractions of fragments weighing more than M_J (grains) were calculated from

$$W(m) = \exp\left\{-(m/\mu)^{1/2}\right\}\left[(1/2)(m/\mu) + (m/\mu)^{1/2} + 1\right]. \qquad (84)$$

[9] See R. W. Gurney and J. N. Sarmousakis, "The Mass Distribution of Fragments from Bombs, Shells, and Grenades," Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, BRL Report No. 448, 7 Feb 1944.

Equation (84) is gotten from (81) and (see Ref.6)

$$W(m) = \int_0^{N(m)} m \, dN \; .$$

IV RESULTS

About 12 computations were made with the fluid dynamics section of the program in order to test the effect of the grid size on the calculated velocities. These were done for metal cylinders 40 cm long and 10 cm inside diameter, with uncapped ends, filled with Grade A Composition B explosive, and plane detonated at one end. Explosive to metal masses (C/M) between 0.1 and 2.0 were tried. The JWL equation of state, with the explosive constants for Grade A Composition B taken from Ref. 6, was used. Calculations were made for 20x3, 40x6, and 80x12 grids, e.g., in the 20x3 grid the cells were 2 cm in the axial direction and 5/3 cm in the radial direction. Typical machine times for the computation of expansions to 2-3 radii, with the CDC 6400 computer, were 45 seconds for the 20x3 grid, 3 minutes for the 40x6 grid and 15 minutes for the 80x12 grid.

Figure 12 shows the effect of cell size on the calculated velocity, which is given in terms of the Gurney value, viz.,

$$\text{Gurney value} = (U^2+V^2)^{1/2}\left[(1+0.5\,C/M)/(C/M)\right]^{1/2}.$$

These computations were made for C/M=0.2, a value like that encountered in projectiles. The plots in Fig.12 are for various expansions, R/R_0, where R_0 is the initial inside radius (=5 cm here). Note in the figure that the velocities calculated with the 2 cm long cell (20x3 grid) are close to those obtained with the finer grids. As the C/M ratio is made larger, corresponding to thinner walls and more rapid expansion, the effect of cell size becomes greater. For C/M=2.0, wall velocities calculated with the 20x3 grid are about 3% lower than those calculated with the 80x12 grid.

Sample weapon calculations were made for the 105 mm, M1, and the 155 mm, M107, projectiles, with standard projectile steel casings, filled with military grade Composition B explosive (RDX/TNT/wax, 59.4/39.6/1.0). The JWL equation (13) with the following values of the constants was used:

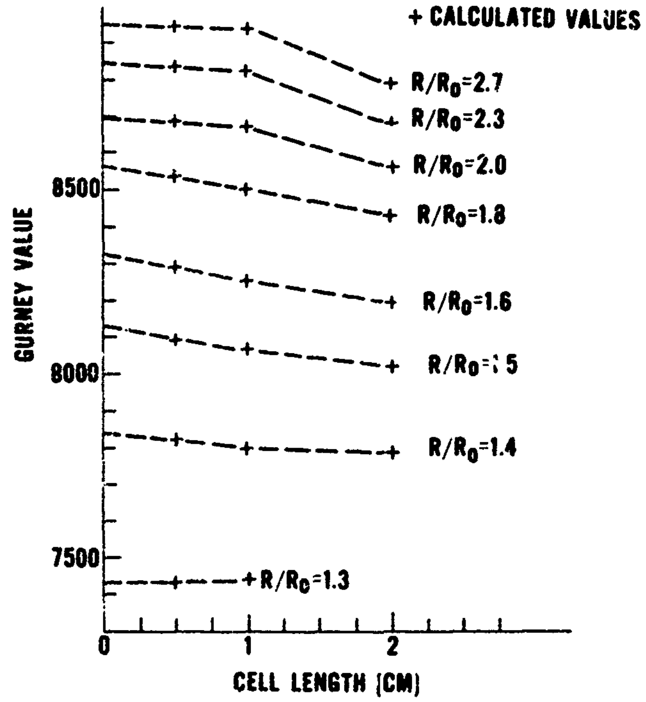

FIG. 12 EFFECT OF CELL SIZE ON CALCULATED VELOCITY (40 CM LONG BY 10 CM INSIDE DIAMETER METAL TUBE; 28 CM FROM INITIATION END, C/M=0.2)

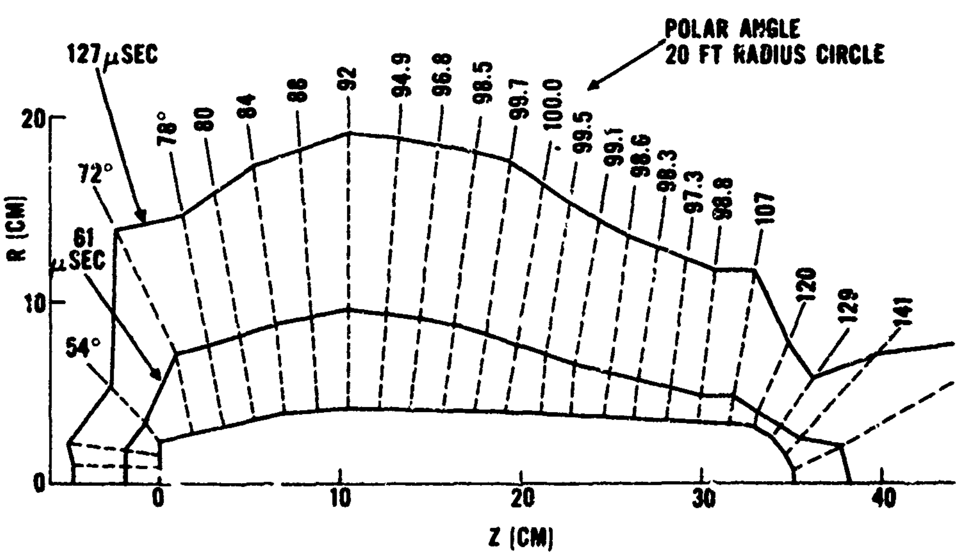

FIG. 13 105 MM PROJECTILE. CALCULATED DIRECTIONS OF METAL MOTION

$D = 0.7839$ cm/usec , $\rho_o = 1.634$ grams/cc,

$E1 = 0.0814$ mb-cc/cc $(= \tilde{E1}\,\rho_o)$,

$D2 = 0.30$, $D3 = 4.9055$, $D4 = 0.058$,

$F1 = 4.2$, , $F2 = 0.9$.

The above values, worked out for a different RDX containing explosive, are believed to be adequate for military grade Composition B. The density used (1.634 g/cc) may be a bit low, but this should not be significant. The maximum reported experimental density for cast Composition B is 1.68 g/cc.

Figure 13 shows the calculated directions of the various sections of the 105 mm projectile at two different times. Note that a large fraction of the metal, usually called the beam spray, appears in the 20th polar zone (95-100°), and that the directions are fairly well stabilized after about 60 microseconds from the initiation time.

The input and the calculated weight, velocity and angular distributions of fragments from the 105 mm, M1, and the 105 mm, M107, shells are listed in Tables I through XII. Tables I and II give the C/M ratios, the inside radii, the scale factors χ , and the values of $\overline{M}$ assigned to the mass points (see Sec.III). The initial grid and the calculated results are Tables III-VII for the 105 mm shell and in Tables VIII-XII for the 155 mm shell. It was pointed out in Sec.III that the calculated velocities can vary by a few percent depending upon the assumption made about when the acceleration ceases. For each 5 degree polar zone, the calculated numbers of fragments in the various weight ranges are listed in Tables VII and XII.

TABLE I C/M RATIOS, INSIDE RADII (CM), AND SCALE FACTORS X ($IN^{4/3}$) FOR 105 MM, M1, AND 155 MM, M107 SHELLS.

105 MM SHELL, M1. HE LOADING DENSITY=1.634 GRAMS/CC

C/M AND SCALE FACTOR
X=ST*DI**(1/3)/(1+2*C/M)

K	Z(K,0)	IR(CM)	C/M	CHI(IN**4/3)
1	0	2.35	.123762	.58116
2	1.755	2.775	.15489	.575323
3	3.51	3.2	.187494	.564955
4	5.265	3.525	.23135	.504983
5	7.02	3.85	.283879	.443403
6	8.775	4.025	.315046	.411023
7	10.53	4.2	.351818	.37873
8	12.285	4.215	.346186	.388644
9	14.04	4.23	.340754	.398612
10	15.795	4.15	.325526	.412235
11	17.55	4.07	.310954	.425875
12	19.305	3.965	.273072	.483807
13	21.06	3.86	.241224	.542416
14	22.815	3.755	.21493	.599715
15	24.57	3.65	.192151	.655058
16	26.325	3.55	.173139	.708544
17	28.08	3.45	.15631	.761675
18	29.835	3.36	.137018	.844104
19	31.59	3.27	.120679	.925896
20	32.9	3.03	.112634	.915206
21	35.1	2.55	7.13284E-2	1.09668

155 MM SHELL, M107. HE LOADING DENSITY=1.634 GRAMS/CC

C/M AND SCALE FACTOR
X=ST*DI**(1/3)/(1+2*C/M)

K	Z(K,0)	IR(CM)	C/M	CHI(IN**4/3)
1	4	2.6	.152479	.536315
2	6.6295	3.23	.206232	.513635
3	9.259	3.75	.241187	.522
4	11.8885	4.22	.265091	.545188
5	14.518	4.65	.289112	.557504
6	17.1475	5	.306671	.570282
7	19.777	5.35	.33861	.549701
8	22.4065	5.6	.330727	.602287
9	25.036	5.81	.32352	.650773
10	27.6655	6	.31588	.700387
11	30.295	6.12	.345283	.641166
12	32.9245	6.12	.357498	.612645
13	35.554	6.05	.336248	.653534
14	38.1835	5.92	.301288	.730476
15	40.813	5.7	.252668	.862817
16	43.4425	5.45	.209228	1.01484
17	46.072	5.17	.171087	1.18497
18	48.7015	4.9	.14184	1.34689
19	51.331	4.61	.107618	1.63807
20	53.9605	4.35	.100756	1.61515
21	56.59	4.1	9.79935E-2	1.53253

TABLE II $\bar{M}$ VS MS. AVERAGE WEIGHT OF FRAGMENTS WEIGHING MORE THAN ONE GRAIN ASSIGNED TO MASS POINTS

105 MM SHELL, M1 COMPOSITION B FILL		155 MM SHELL, M107 COMPOSITION B FILL	
MS	MBAR (GRAINS)	MS	MBAR (GRAINS)
1	200	1	200
2	200	2	200
3	200	3	200
4	105	4	90
		5	80
		6	85
		7	90
		8	95
5	105	9	100
6	100	10	95
7	75	11	110
8	55	12	130
9	40	13	145
10	30	14	125
11	35	15	115
12	35	16	130
13	45	17	150
14	50	18	185
15	70	19	210
16	95	20	230
17	110	21	245
18	130	22	270
19	145	23	100
20	160	24	45
21	180	25	80
22	65	26	100
23	65	27	136
24	20		
25	35		
26	45		
27	45		

TABLE III 105 MM SHELL M1 (NOSE PLUG). INITIAL GRID, INCLUDING METAL OUTER BOUNDARY POINTS

L	K	Z (CM)	R (CM)
0	0	-3.15	0
0	1	0	0
0	2	1.755	0
0	3	3.51	0
0	4	5.265	0
0	5	7.02	0
0	6	8.775	0
0	7	10.53	0
0	8	12.285	0
0	9	14.04	0
0	10	15.795	0
0	11	17.55	0
0	12	19.305	0
0	13	21.06	0
0	14	22.815	0
0	15	24.57	0
0	16	26.325	0
0	17	28.08	0
0	18	29.835	0
0	19	31.59	0
0	20	32.9	0
0	21	35.1	0
0	22	36.9	0
1	0	-3.15	1
1	1	0	.783333
1	2	1.755	.925
1	3	3.51	1.06667
1	4	5.265	1.175
1	5	7.02	1.28333
1	6	8.775	1.34167
1	7	10.53	1.4
1	8	12.285	1.405
1	9	14.04	1.41
1	10	15.795	1.38333
1	11	17.55	1.35667
1	12	19.305	1.32167
1	13	21.06	1.28667
1	14	22.815	1.25167
1	15	24.57	1.21667
1	16	26.325	1.18333
1	17	28.08	1.15
1	18	29.835	1.12
1	19	31.59	1.09
1	20	32.9	1.02667
1	21	35.1	.85
1	22	36.9	.85
2	0	-3.15	2
2	1	0	1.56667
2	2	1.755	1.85
2	3	3.51	2.13333
2	4	5.265	2.35
2	5	7.02	2.53667
2	6	8.775	2.68333
2	7	10.53	2.8
2	8	12.285	2.81
2	9	14.04	2.82
2	10	15.795	2.78667
2	11	17.55	2.71333
2	12	19.305	2.64333
2	13	21.06	2.57333
2	14	22.815	2.50333
2	15	24.57	2.43333
2	16	26.325	2.36667
2	17	28.08	2.3
2	18	29.835	2.24
2	19	31.59	2.18
2	20	32.9	2.05333
2	21	34.62	1.7
2	22	36.9	1.7
3	0	-3.15	3
3	1	0	2.35
3	2	1.755	2.775
3	3	3.51	3.2
3	4	5.265	3.525
3	5	7.02	3.85
3	6	8.775	4.025
3	7	10.53	4.2
3	8	12.285	4.215
3	9	14.04	4.23
3	10	15.795	4.15
3	11	17.55	4.07
3	12	19.305	3.965
3	13	21.06	3.86
3	14	22.815	3.755
3	15	24.57	3.65
3	16	26.325	3.55
3	17	28.08	3.45
3	18	29.835	3.36
3	19	31.59	3.27
3	20	32.9	3.08
3	21	33.87	2.55
3	22	36.9	2.55
4	0	-3.15	[illegible]
4	1	0	[illegible]
4	2	1.755	4.25
4	3	3.51	4.65
4	4	5.265	4.86
4	5	7.02	5.07
4	6	8.775	5.185
4	7	10.53	5.3
4	8	12.285	5.335
4	9	14.04	5.37
4	10	15.795	5.315
4	11	17.55	5.28
4	12	19.305	5.265
4	13	21.06	5.27
4	14	22.815	5.27
4	15	24.57	5.27
4	16	26.325	5.27
4	17	28.08	5.27
4	18	29.835	5.335
4	19	31.59	5.4
4	20	32.9	5.2
4	21	33.87	5.05
4	22	36.9	4.57

TABLE IV 105 MM SHELL M1 (NOSE PLUG). COMPOSITION B FILL. CALCULATED SCALED MASSES, AND POLAR ANGLES 120 MICROSECONDS AFTER INITIATION

M5	K	L	W6 (MASS/2 π, GRAMS)	A9 (M5 + 1/2) (DEG)
1	1	0	2.46646	0
2	1	1	19.7316	3.83063
3	1	2	39.4633	24.6653
4	1	3	118.884	32.4021
5	2	3	71.2737	70.0966
6	3	3	77.3143	77.2066
7	4	3	76.9748	79.2662
8	5	3	75.0088	82.9095
9	6	3	73.4889	85.8319
10	7	3	72.3137	91.0764
11	8	3	73.5848	94.1842
12	9	3	75.1496	96.2043
13	10	3	75.8575	97.9619
14	11	3	77.0958	99.2899
15	12	3	92.542	99.7702
16	13	3	88.5115	99.5339
17	14	3	94.0576	99.2677
18	15	3	99.3756	99.0519
19	16	3	104.361	98.8357
20	17	3	109.708	98.3463
21	18	3	118.139	99.3487
22	19	3	117.75	107.034
23	20	3	116.274	121.804
24	21	3	146.252	135.989
25	21	2	76.6558	147.4
26	21	1	25.0097	166.651

TABLE V 105 MM SHELL M1 (NOSE PLUG). COMPOSITION B FILL. CALCULATED WEIGHT CONTRIBUTIONS OF MASS POINTS TO 5 DEGREE POLAR ZONES, 120 MICROSECONDS AFTER INITIATION

MASS PT	POLAR ZONE	WT IN ZONE(GRAINS)
1	1	238.944
2	1	1911.55
3	1	214.576
3	2	917.495
3	3	917.485
3	4	917.485
3	5	856.066
4	5	138.983
4	6	2076.15
4	7	2076.15
4	8	2076.15
4	9	2076.15
4	10	2076.15
4	11	997.443
5	11	1013.75
5	12	1951.12
5	13	1951.12
5	14	1951.12
5	15	37.7108
6	15	5122.24
6	16	2367.76
7	16	7457.11
8	16	1504.97
8	17	5761.68
9	17	3877.1
9	18	3242.31
10	18	5229.01
10	19	1776.54
11	19	7128.69
12	19	2940.14
12	20	4340.15
13	20	7348.87
14	20	7468.83
15	20	7996.45
16	20	8574.76
17	20	9112.04
18	20	9627.23
19	20	10110.2
20	20	10628.2
21	20	11444.9
22	20	966.708
22	21	7421.35
22	22	3019.26
23	22	2261.93
23	23	3813.33
23	24	3913.33
23	25	1375.77
24	25	3192.34
24	26	6994.11
24	27	4994.11
24	28	987.99
25	28	2610.34
25	29	3254.1
25	30	1561.76
26	30	327.257
26	31	629.261
26	32	629.261
26	33	629.261
26	34	207.234
27	34	30.9731
27	35	46.248
27	36	46.248
27	37	0

TOT METAL WT= 29.1812 LB(204268. GRAINS)

TABLE VI 105 MM SHELL M1 (NOSE PLUG). COMPOSITION B FILL. CALCULATED FRAGMENT WEIGHT, PERCENT OF TOTAL METAL WEIGHT, AND AVERAGE VELOCITY IN EACH 5 DEGREE POLAR ZONE, 120 MICROSECONDS AFTER INITIATION

POLAR ZONE	MET WT (GRAINS)	PCT BY WT	AV VEL (FT/SEC)
1	2365.07	1.15783	1412.25
2	917.485	.449158	1629.81
3	917.485	.449158	1629.81
4	917.485	.449158	1629.81
5	995.049	.48713	1598.46
6	2076.15	1.01639	1405.39
7	2076.15	1.01639	1405.39
8	2076.15	1.01639	1405.39
9	2076.15	1.01639	1405.39
10	2076.15	1.01639	1405.39
11	2011.19	.984585	2694.58
12	1951.12	.955177	3963.04
13	1951.12	.955177	3963.04
14	1951.12	.955177	3963.04
15	5159.95	2.52608	3808.16
16	11329.8	5.54657	4009.29
17	9633.78	4.7187	4480.45
18	8471.32	4.14717	4760.44
19	11845.4	5.79895	4801.33
20	87618.4	42.8939	4014.62
21	7421.35	3.63315	3398.29
22	5281.19	2.58543	3116.71
23	3813.33	1.86683	2740.86
24	3813.33	1.86683	2740.86
25	4568.11	2.23633	2136.48
26	4994.11	2.44489	1876.01
27	4994.11	2.44489	1876.01
28	3598.33	1.76158	2326.37
29	3254.1	1.59306	2496.82
30	1889.02	.924775	2704.8
31	629.261	.308057	3697.35
32	629.261	.308057	3697.35
33	629.261	.308057	3697.35
34	238.807	.116909	4263.84
35	46.248	2.26409E-2	8065.03
36	46.248	2.26409E-2	8065.03

TABLE VII 105 MM SHELL, M1 (NOSE PLUG). CALCULATED NUMBERS OF FRAGMENTS IN VARIOUS WEIGHT RANGES IN EACH 5 DEGREE POLAR ZONE, 120 MICROSECONDS AFTER INITIATION

NO. OF FRAGMENTS IN POLAR ZONES
WT. RANGES IN GRAINS

POLAR ZONE	1 - 2	2 - 5	5 - 10	10 - 15
1	.505183	.939352	.965533	.67953
2	.195977	.364404	.374561	.263611
3	.195977	.364404	.374561	.263611
4	.195977	.364404	.374561	.263611
5	.260085	.481361	.489483	.341103
6	1.16559	2.11153	2.09129	1.4212
7	1.16559	2.11153	2.09129	1.4212
8	1.16559	2.11153	2.09129	1.4212
9	1.16559	2.11153	2.09129	1.4212
10	1.16559	2.11153	2.09129	1.4212
11	1.12912	2.04546	2.02585	1.37673
12	1.09539	1.98436	1.96534	1.33561
13	1.09539	1.98436	1.96534	1.33561
14	1.09539	1.98436	1.96534	1.33561
15	3.11756	5.63415	5.26116	3.75714
16	13.7147	19.818	18.2987	12.1029
17	18.3369	31.5387	29.0132	18.3922
18	28.6047	46.6738	41.8416	24.926
19	37.2258	62.3308	55.1646	33.7022
20	74.0183	131.227	124.326	81.1726
21	8.08674	15.3167	14.5913	9.55963
22	6.18167	10.8983	10.3835	6.8027
23	4.46352	7.8692	7.69748	4.91194
24	4.46352	7.8692	7.69748	4.91194
25	24.6642	39.1024	32.0391	19.2289
26	36.0657	56.7306	65.8906	25.7325
27	36.0657	56.7306	65.8906	25.7325
28	15.0244	24.47	20.8486	12.3078
29	9.83526	16.5139	14.6727	8.93701
30	5.39762	9.08784	9.10724	4.99078
31	1.30242	2.23493	2.0484	1.29368
32	1.30242	2.23493	2.0484	1.29368
33	1.30242	2.23493	2.0484	1.29368
34	.494273	.848126	.777377	.490958
35	9.57221E-2	.16425	.150549	9.50802E-2
36	9.57221E-2	.16425	.150549	9.50802E-2

POLAR ZONE	150 - 250	GT. THAN 250
1	1.13157	2.44169
2	.438974	.962725
3	.438974	.962725
4	.438974	.962725
5	.511414	1.0449
6	1.52111	2.19022
7	1.52111	2.19022
8	1.52111	2.19022
9	1.52111	2.19022
10	1.52111	2.19022
11	1.47351	2.12140
12	1.4295	2.05031
13	1.4295	2.05031
14	1.4295	2.05031
15	3.07214	5.39117
16	9.38067	10.7513
17	8.44285	6.81859
18	6.73221	3.9982
19	9.59132	5.73179
20	61.7791	84.2295
21	6.46809	6.55581
22	4.59714	4.66468
23	3.3194	3.38817
24	3.3194	3.38817
25	2.81998	1.77795
26	2.53811	.880412
27	2.53811	.880412
28	2.6487	1.47616
29	2.666	1.62388
30	1.56718	.99585
31	.553143	.417019
32	.553143	.417019
33	.553143	.417019
34	.20992	.15826
35	4.06537E-2	3.08491E-2
36	4.06537E-2	3.08491E-2

PZ	15 - 25	25 - 50	50 - 100	100 - 150
1	.978451	1.52127	1.65629	.965886
2	.379572	.590151	.642529	.374698
3	.379572	.590151	.642529	.374698
4	.379572	.590151	.642529	.374698
5	.485942	.742309	.787486	.44764
6	1.96855	2.86313	2.80792	1.45432
7	1.96855	2.86313	2.80792	1.45432
8	1.96855	2.86313	2.80792	1.45432
9	1.96855	2.86313	2.80792	1.45432
10	1.96855	2.86313	2.80792	1.45432
11	1.90695	2.77354	2.72006	1.4155
12	1.84949	2.69069	2.63881	1.37613
13	1.84999	2.69069	2.63881	1.37613
14	1.84999	2.69069	2.63881	1.37613
15	5.1995	7.51636	7.30135	3.76871
16	16.2745	22.5108	20.436	9.62377
17	23.6071	30.1646	24.1956	10.1696
18	30.5305	36.027	25.5066	9.34198
19	41.5353	49.4953	35.5243	13.1779
20	107.831	146.807	131.589	63.3716
21	12.7171	17.2593	15.1863	7.04298
22	9.04973	12.2821	10.8069	5.01193
23	6.53443	8.86836	7.80316	3.6189
24	6.53443	9.45836	7.80316	3.6189
25	20.828	26.0844	13.3491	4.28102
26	29.8954	29.4196	16.4792	4.62344
27	28.8954	29.4186	16.4792	4.62344
28	14.6459	16.5298	11.0224	3.82392
29	11.1317	13.3512	9.6766	3.62674
30	6.4022	7.49705	5.50471	2.09534
31	1.65312	2.09461	1.65473	.682108
32	1.65312	2.09461	1.65473	.682108
33	1.65312	2.09461	1.65473	.682108
34	.627366	.794914	.627478	.259863
35	.121497	.153945	.121618	.050132
36	.121497	.153945	.121618	.050132

TABLE VIII 155 MM SHELL, M107 (M51A5 FUZE). INITIAL GRID, INCLUDING METAL OUTER BOUNDARY POINTS

L	K	Z (CM)	R (CM)	L	K	Z (CM)	R (CM)
0	0	-3	0	2	11	30.295	4.08
0	1	4	0	2	12	32.9245	4.08
0	2	6.6295	0	2	13	35.554	4.03333
0	3	9.259	0	2	14	38.1835	3.96667
0	4	11.8885	0	2	15	40.813	3.8
0	5	14.518	0	2	16	43.4425	3.63333
0	6	17.1475	0	2	17	46.072	3.44667
0	7	19.777	0	2	18	48.7015	3.26667
0	8	22.4065	0	2	19	51.331	3.07333
0	9	25.036	0	2	20	53.9605	2.9
0	10	27.6655	0	2	21	56.59	2.73333
0	11	30.295	0	2	22	60.45	2.73333
0	12	32.9245	0	3	0	-3	2
0	13	35.554	0	3	1	4	2.6
0	14	38.1835	0	3	2	6.6295	3.23
0	15	40.813	0	3	3	9.259	3.75
0	16	43.4425	0	3	4	11.8885	4.22
0	17	46.072	0	3	5	14.518	4.65
0	18	48.7015	0	3	6	17.1475	5
0	19	51.331	0	3	7	19.777	5.35
0	20	53.9605	0	3	8	22.4065	5.6
0	21	56.59	0	3	9	25.036	5.81
0	22	60.45	0	3	10	27.6655	6
1	0	-3	.666667	3	11	30.295	6.12
1	1	4	.866667	3	12	32.9245	6.12
1	2	6.6295	1.07667	3	13	35.554	6.05
1	3	9.259	1.25	3	14	38.1835	5.92
1	4	11.8885	1.40667	3	15	40.813	5.7
1	5	14.518	1.55	3	16	43.4425	5.45
1	6	17.1475	1.66667	3	17	46.072	5.17
1	7	19.777	1.78333	3	18	48.7015	4.9
1	8	22.4065	1.86667	3	19	51.331	4.61
1	9	25.036	1.93667	3	20	53.9605	4.35
1	10	27.6655	2	3	21	56.59	4.1
1	11	30.295	2.04	3	22	60.45	4.1
1	12	32.9245	2.04	4	0	-3	2.3
1	13	35.554	2.01667	4	1	4	4
1	14	38.1835	1.97333	4	2	6.6295	4.58
1	15	40.813	1.9	4	3	9.259	5.12
1	16	43.4425	1.81667	4	4	11.8885	5.64
1	17	46.072	1.72333	4	5	14.518	6.1
1	18	48.7015	1.63333	4	6	17.1475	6.48
1	19	51.331	1.53667	4	7	19.777	6.8
1	20	53.9605	1.45	4	8	22.4065	7.15
1	21	56.59	1.36667	4	9	25.036	7.45
1	22	60.45	1.36667	4	10	27.6655	7.73
2	0	-3	1.33333	4	11	30.295	7.75
2	1	4	1.73333	4	12	32.9245	7.7
2	2	6.6295	2.15333	4	13	35.554	7.7
2	3	9.259	2.5	4	14	38.1835	7.7
2	4	11.8885	2.81333	4	15	40.813	7.7
2	5	14.518	3.1	4	16	43.4425	7.7
2	6	17.1475	3.33333	4	17	46.072	7.7
2	7	19.777	3.56667	4	18	48.7015	7.7
2	8	22.4065	3.73333	4	19	51.331	7.9
2	9	25.036	3.87333	4	20	53.9605	7.62
2	10	27.6655	4	4	21	56.59	7.25
				4	22	60.45	6.7

TABLE IX 155 MM SHELL, M107 (M51A5 FUZE). COMPOSITION B FILL. CALCULATED SCALED MASSES, AND POLAR ANGLES 121 MICROSECONDS AFTER INITIATION

M5	K	L	W6 (MASS/2 π, GRAINS)	A9 (M5+1/2)
1	1	0	4.05502	0
2	1	1	32.4402	3.37265
3	1	2	64.8804	25.2768
4	1	3	226.859	54.7868
5	2	3	109.105	73.9444
6	3	3	125.507	82.9255
7	4	3	143.915	83.9218
8	5	3	160.392	85.0536
9	6	3	174.13	86.5071
10	7	3	183.516	89.0314
11	8	3	203.406	90.7568
12	9	3	224.107	91.1007
13	10	3	240.752	91.9013
14	11	3	233.526	94.527
15	12	3	227.169	97.9178
16	13	3	234.781	100.446
17	14	3	251.239	102.447
18	15	3	276.638	103.568
19	16	3	305.338	103.874
20	17	3	335.43	103.814
21	18	3	367.824	103.911
22	19	3	414.098	103.122
23	20	3	504.858	113.303
24	21	3	446.749	148.8
25	21	2	211.511	173.842
26	21	1	56.5234	177.269

TABLE X 155 MM SHELL, M107 (M51A5 FUZE). COMPOSITION B FILL, CALCULATED WEIGHT CONTRIBUTIONS OF MASS POINTS TO 5 DEGREE POLAR ZONES, 121 MICROSECONDS AFTER INITIATION

MASS PT	POLAR ZONE	WT IN ZONE(GRAINS)
1	1	392.84
2	1	3142.72
3	1	466.972
3	2	1434.76
3	3	1434.76
3	4	1434.76
3	5	1434.76
3	6	79.4232
4	6	3517.6
4	7	3723.73
4	8	3723.73
4	9	3723.73
4	10	3723.73
4	11	3564.96
5	11	117.628
5	12	2758.65
5	13	2758.65
5	14	2758.65
5	15	2176.22
6	15	1445.23
6	16	6845.27
6	17	3968.28
7	17	13942.1
8	17	14802.6
8	18	725.808
9	18	16869.2
10	18	17778.6
11	18	11062.2
11	19	8643.27
12	19	21710.9
13	19	23323.4
14	19	22623.3
15	19	3163.35
15	20	18844.1
16	20	18885.1
16	21	3859.78
17	21	24339.4
18	21	26799.9
19	21	29580.3
20	21	32495.5
21	21	35633.8
22	21	40116.7
23	21	10808.9
23	22	29779.3
23	23	19008.7
24	23	2069.65
24	24	6096.17
24	25	6096.17
24	26	6096.17
24	27	6096.17
24	28	6095.17
24	29	6096.17
24	30	4633.16
25	30	951.858
25	31	4091.29
25	32	4091.29
25	33	4091.29
25	34	4091.29
25	35	3143.64
26	35	1850.23
26	36	3625.6
27	36	684.48
27	37	0

TOT METAL WT= 81.1806 LB(568264. GRAINS)

TABLE XI 155 MM SHELL, M107 (M51A5 FUZE). COMPOSITION B FILL. CALCULATED FRAGMENT WEIGHT, PERCENT OF TOTAL METAL WEIGHT, AND AVERAGE VELOCITY IN EACH 5 DEGREE POLAR ZONE, 121 MICROSECONDS AFTER INITIATION

POLAR ZONE	MET WT (GRAINS)	PCT BY WT	AV VEL (FT/SEC)
1	4002.53	.704343	1159.48
2	1434.76	.252481	1304.8
3	1434.76	.252481	1304.8
4	1434.76	.252481	1304.8
5	1434.76	.252481	1304.8
6	3597.02	.632984	1226.37
7	3723.73	.655282	1224.6
8	3723.73	.655282	1224.6
9	3723.73	.655282	1224.6
10	3723.73	.655282	1224.6
11	3682.58	.648041	1341.57
12	2758.65	.485453	4886.54
13	2758.65	.485453	4886.54
14	2758.65	.485453	4886.54
15	3621.46	.637284	4694.05
16	6845.27	1.20459	4404.2
17	32612.9	5.73904	4168.55
18	46445.8	8.17327	4385.27
19	79464.3	13.9837	4405.34
20	37729.3	6.63938	4810.68
21	203634.	35.8345	3594.76
22	28779.3	5.06442	2245.96
23	21078.4	3.70926	2233.1
24	6096.17	1.07277	2115.02
25	6096.17	1.07277	2115.02
26	6096.17	1.07277	2115.02
27	6096.17	1.07277	2115.02
28	6096.17	1.07277	2115.02
29	6096.17	1.07277	2115.02
30	5615.02	.9881	2206.7
31	4091.29	.719962	2639.32
32	4091.29	.719962	2639.32
33	4091.29	.719962	2639.32
34	4091.29	.719962	2639.32
35	4993.87	.878794	3372.22
36	4310.08	.758465	4615.4

TABLE XII 155 MM SHELL, M107 (M51A5 FUZE). CALCULATED NUMBERS OF FRAGMENTS IN VARIOUS WEIGHT RANGES IN EACH 5 DEGREE POLAR ZONE, 121 MICROSECONDS AFTER INITIATION

NO. OF FRAGMENTS IN POLAR ZONES
WT. RANGES IN GRAINS

PZ	1 - 2	2 - 5	5 - 10	10 - 15
1	.454949	1.50971	1.61602	1.15
2	.300460	.564856	.585737	.612234
3	.300460	.564846	.585737	.612234
4	.300464	.564856	.585737	.612234
5	.300464	.564846	.585737	.612234
6	2.53276	4.51746	4.62584	2.97715
7	2.60295	4.74879	4.65092	3.12746
8	2.60295	4.74674	4.65092	3.12746
9	2.60205	4.74674	4.65092	3.12746
10	2.60295	4.74874	4.65092	3.12746
11	2.62437	4.72476	4.6257	3.19951
12	2.36360	4.18471	4.60684	2.71652
13	2.34366	4.1 71	4.6 684	2.70652
14	2.34366	4.15471	4.60684	2.70652
15	2.96758	5.30606	5.15066	3.44612
16	5.24457	9.64544	5.25942	6.29012
17	22.5549	40.4916	[illegible]	24.7966
18	28.9064	53.7659	50.4763	33.4145
19	32.7731	59.8136	60.011	41.2839
20	16.9836	30.9296	30.4385	21.1441
21	49.1443	93.6026	95.4404	58.4934
22	17.347	31.44	31.632	21.822[illegible]
23	15.7746	29.1165	27.2230	16.1391
24	12.6179	21.6506	19.8445	12.333
25	12.6176	21.6506	19.8445	12.533
26	12.6176	21.6506	19.8445	12.533
27	12.6176	21.6596	19.8445	12.333
28	12.6176	21.6[illegible]	19.8445	12.533
29	12.6176	21.6596	19.8445	12.533
30	10.4736	17.4461	16.5273	10.4885
31	3.47553	6.20023	6.022	6.01397
32	3.47593	6.20623	6.022	6.01397
33	3.47553	6.20673	6.022	6.01397
34	3.47553	6.20023	6.022	6.01397
35	3.70897	6.74	6.62221	6.63509
36	2.90566	4.78895	4.64745	3.16012

PZ	15 - 25	25 - 50	50 - 100	100 - 150
1	1.45509	2.51453	2.40304	1.63462
2	.593573	.922876	1.00474	.905951
3	.593573	.922876	1.00476	.905951
4	.593573	.922876	1.00476	.905951
5	.593573	.922876	1.004 1	.905951
6	4.07753	5.81719	5.59625	2.79531
7	4.28169	6.10394	5.80126	2.92470
8	4.28169	6.10394	5.80126	2.92470
9	4.28169	6.10394	5.80126	2.92470
10	4.28169	6.10394	5.80126	2.92470
11	4.27559	5.06426	5.75704	2.89464
12	3.66962	5.14508	4.76409	2.33517
13	3.66962	5.145 8	4.76409	2.33317
14	3.66962	5.14508	4.76409	2.33517
15	4.67874	4.50192	5.12656	3.42029
16	8.44925	11.9361	11.2174	5.59814
17	36.7175	52.4557	50.0227	23.3133
18	46.7989	67.6250	55.6648	33.9819
19	57.9641	6.2996	87.0079	47.5483
20	29.3052	43.706	44.1343	23.7059
21	85.694	132.127	142.224	69.1186
22	29.5125	61.305	40.7361	21.0751
23	24.5949	35.5496	32.3486	16.1305
24	16.0151	20.2922	16.0307	6.60813
25	16.0151	20.2922	16.0307	6.60813
26	16.0151	20.2922	16.0307	6.60813
27	16.6151	20.2922	16.0307	6.60812
28	16.0151	20.2922	16.0307	6.60813
29	16.0151	20.2922	16.0307	6.60813
30	13.4774	17.2536	13.8792	5.8536
31	5.44232	7.63053	7.0655	3.46323
32	5.44232	7.63053	7.0655	3.46323
33	5.44232	7.63053	7.0655	3.46323
34	5.44232	7.63053	7.0655	3.46323
35	6.09696	8.55934	8.04700	4.01277
36	4.345	6.20894	6.10077	3.14870

POLAR ZONE	150 - 250	GT. THAN 250
1	1.91582	4.19989
2	.686465	1.50551
3	.686465	1.50551
4	.686465	1.39951
5	.686465	1.50551
6	4.0864	3.06097
7	2.93063	3.78717
8	2.93063	3.79717
9	2.93063	3.79717
10	2.93063	3.79717
11	2.4925	3.7606
12	2.27640	2.6940
13	2.27680	2.6949
14	2.27080	2.3949
15	2.95522	3.56936
16	5.81222	6.13677
17	25.4365	33.3224
18	34.8843	49.6955
19	51.6652	85.6727
20	53.6246	49.9038
21	95.4226	209.173
22	21.6906	30.6068
23	16.0863	23.2347
24	9.75372	4.04
25	5.35875	4.04
26	5.35875	4.04
27	5.35875	4.04
28	5.35875	4.04
29	5.35875	4.04
30	4.88097	4.02962
31	3.36709	3.99673
32	3.36709	3.99673
33	3.36709	3.99673
34	3.36709	3.99673
35	3.97669	4.08399
36	3.23494	4.5829

Appendix A - The Fragment Prediction Code

Table AI is a complete list of the computer program, in BASIC. A set of notes, which explain what the various statements do, is in Table AII. Table AIII is a list of variables, together with the quantities needed in the dimension statements. Figures A1-A3 illustrate descriptions in the notes. The particular weapon treated in the program list (Table AI) is the 105 mm, M1 shell. For other items, which do not have a curved base, the input is somewhat simpler and some of the statements can be removed. Table AIV is a list of the input statements. To run the program for a particular weapon one proceeds through this list, providing the necessary data at the listed statement numbers and removing or bypassing any statements that do not apply. Parts of the program, for example, the initialization to get values of the scale factor X , or the fluid dynamics, can be run by inserting appropriate bypass or exit statements. Output statements are listed in Table AV. Since all the statements in BASIC are numbered, any of the output can be bypassed by inserting a GO TO statement at the appropriate place.

It will be seen in Tables AI and AV that there are provisions for output in formats needed by lethal area programs. For the JMEM lethal area program, the necessary calculated quantities are put on tape, from which a card deck in the appropriate format is prepared. The FORTRAN program which determines how this card deck is made is listed in Table AVI. For the AMSAA lethal area program, the necessary input quantities are listed. Provisions for getting a card deck for this program, and for machine plotting of any of the output, could be added by putting the needed material on tape and using auxiliary FORTRAN routines.

TABLE A-1 BASIC PROGRAM LIST-FRAGMENT PREDICTION CODE

```
01000 PRINT"105 MM"
01010 P9=3.14159265
01020 P6=2*P9
01030 Q9=P6*15.4185
01040 P7=5*P9/180
01050 P8=P6/454
01060 REM NO. OF STERADIANS IN POLAR ZONE
01070 FOR J6=1 TO 18
01080 Y8(J6)=P6*(COS((J6-1)*P7)-COS(J6*P7))
01090 Y8(37-J6)=Y8(J6)
01100 NEXT J6
01110 J9=10
01120 T7=40
01130 T4=150
01140 T1=0.3
01150 E8=1.1
01160 N4=20
01170 N5=7
01180 N6=200
01190 N7=1
01200 K4=0
01210 R2=4
01220 R4=7.84
01230 C3=2
01240 E7=1E-10
01250 D1=20
01270 R0=0
01280 Z0=20
01290 L1=3
01300 K1=21
01305 REM----------BRING IN EQUATION OF STATE CONSTANTS
01310 GOSUB 08450
01320 PRINT"K1="K1,"L1="L1,"K4="K4
01330 PRINT"J9="J9
01340 PRINT"T7="T7,"T4="T4,"T1="T1,"E8="E8,"N5="N5
01350 PRINT"N6="N6,"E7="E7
01360 PRINT"R2="R2,"R4="R4
01370 PRINT"R0="R0,"Z0="Z0,"D1="D1"FT"
01380 DIM N3(37,10),N7(37,10),M1(27),M(10),N(27,10)
01390 DIM W6(27),A9(27),Q3(27)
01400 DIM W7(37,31),W2(27,10),W5(37,10),W8(37),W9(37)
01410 DIM            N8(37),Y8(37),Y9(37),M6(37,10),Q6(37,10)
01420 DIM R(23,7),Z(23,7),R1(20,5),Z1(20,5)
01430 DIM R2(23,7)
01440 DIM W1(20,5),W(23,7)
01450 DIM W3(23,7)
01460 DIM U(23,7),V(23,7),V1(20,5),V5(20,5)
01470 DIM Q1(20,5),T3(20,5),C2(20,5),P2(20,5),E2(20,5)
01480 DIM Y(36),Y1(36),F(20) ,U7(21),V7(21)
01490 DIM         S8(21),R3(21),Z3(21),P3(21)
01500 DIM R4(21),Z4(21),A1(20,5),K9(21)
01510 REM------------------INPUT Z(K1,0),Z(0,0),Z(1,0),Z,K1+1,0)
01520 Z(K1,0)=35.1
01530 Z(0,0)=-3.15
01540 Z(1,0)=0
01550 Z(K1+1,0)=36.9
```

TABLE A-1 (CONT.)

```
01560 REM---------------------------INITIALIZE Z(K,0)-----------------
01570 FOR K=1 TO K1
01580 Z(K,0)=Z(1,0)+(Z(K1,0)-Z(1,0))*(K-1)/(K1-1)
01590 NEXT K
01600 REM ----------------INPUT SPECIAL Z(K,0) VALUES----------------
01610 Z(20,0)=32.9
01620 REM -----------------INPUT R(K,L1),R(K,L1+1)-------------------
01630 GOSUB 09960
01640 REM------------------INPUT SPECIAL R(K,L1),R(K,L1+1) VALUES------
01650 GOSUB 10070
01660 REM -------------------INITIALIZE Z(K,L),R(K,L)----------------
01670 FOR K=0 TO K1+1
01680 FOR L=1 TO L1+1
01690 Z(K,L)=Z(K,0)
01700 NEXT L
01710 FOR L=1 TO L1-1
01720 R(K,L)=R(K,L1)*L/L1
01730 NEXT L
01740 NEXT K
01750 REM------------------INPUT SPECIAL Z(K1,L) VALUES---------------
01760 Z(K1,2)=34.62
01770 Z(K1,L1)=33.87
01780 Z(K1,L1+1)=Z(K1,L1)
01790 REM-----------------WEIGHT DISTRIBUTION INPUT-------------------
1800  GOSUB 21200
01810 REM----------PRINT CASE DIMENSION INPUT-------------
01820 PRINT ≡L≡,≡R≡,≡Z≡,≡R≡
01830 FOR L=0 TO L1+1
01840 FOR K=0 TO K1+1
01850 PRINTL,K,Z(K,L),R(K,L)
01860 NEXT K
01870 NEXT L
01875 REM
01880 REM-------------------INITIALIZE R3(K),Z3(K)-------------------
01890 GOSUB 11040
01900 REM--------------------SET Z FOR LIGHTING----------------------
01910 Z=Z(K4+1,0)
01920 REM ---------INITIALIZE HE AND FUZE DENSITIES------------------
01930 GOSUB 07190
01960 REM------------------COORD OF ZONE CENTERS,ZONE MASSES-----------
01970 FOR K=1 TO K1-1
01980 FOR L=0 TO L1-1
01990 Z1(K,L)=(Z(K,L)+Z(K+1,L)+Z(K+1,L+1)+Z(K,L+1))/4
02000 R1(K,L)=(R(K,L)+R(K+1,L)+R(K+1,L+1)+R(K,L+1))/4
02010 GOSUB 07300
02020 GOSUB 07390
02030 W1(K,L)=W5
02040 NEXT L
02050 NEXT K
02060 REM--------INTERIOR GRID POINT MASSES--------------------------
02070 FOR K=2 TO K1-1
02080 FOR L=1TO L1-1
02090 G1=Z1(K-1,L-1)
02100 H1=R1(K-1,L-1)
02110 G2=Z1(K,L-1)
02120 H2=R1(K,L-1)
```

TABLE A-1 (CONT.)

```
02130 G3=Z1(K,L)
02140 H3=R1(K,L)
02150 G4=Z1(K-1,L)
02160 H4=R1(K-1,L)
02170 GOSUB 07390
02180 W(K,L)=W5
02190 NEXT L
02200 NEXT K
02210 REM--------------------MASSES OF INTERIOR AXIS POINTS-----------
02220 FOR K=2 TO K1-1
02230 L=0
02240 GOSUB 08090
02250 GOSUB 07390
02260 W(K,L)=W5
02270 GOSUB 08180
02280 GOSUB 07390
02290 W(K,L)=W(K,L)+W5
02300 NEXT K
02310 REM-------MASS CORRECTION AT FUZE-HE BOUNDRY--------------------
02320 IF K4=0 THEN 02370
02330 K=K4+1
02340 FOR L=0 TO L1-1
02350 W(K,L)=(R2/R3+1)*W(K,L)/2
02360 NEXT L
02370 REM
02380 REM --------------------GAS MASSES ASSOC WITH METAL POINTS-------
02390 FOR K=2 TO K1-1
02400 L=L1
02410 GOSUB 08270
02420 GOSUB 07390
02430 W3(K,L)=W5
02440 GOSUB 08360
02450 GOSUB 07390
02460 W3(K,L)=W3(K,L)+W5
02470 NEXT K
02480 L=L1
02490 IF K4=0 THEN 02520
02500 K=K4+1
02510 W3(K,L)=(1+R2/R3)*W3(K,L)/2
02520 FOR L=1 TO L1-1
02530 K=1
02540 GOSUB 08090
02550 GOSUB 07390
02560 W3(K,L)=W5
02570 GOSUB 08360
02580 GOSUB 07390
02590 W3(K,L)=W3(K,L)+W5
02600 NEXT L
02610 FOR L=1 TO L1-1
02620 K=K1
02630 GOSUB 08180
02640 GOSUB 07390
02650 W3(K,L)=W5
02660 GOSUB 08270
02670 GOSUB 07390
02680 W3(K,L)=W3(K,L)+W5
```

TABLE A-1 (CONT.)

```
02690 NEXT L
02700 K=1
02710 L=0
02720 GOSUB 08090
02730 GOSUB 07390
02740 W3(K,L)=W5
02750 L=L1
02760 GOSUB 08360
02770 GOSUB 07390
02780 W3(K,L)=W5
02790 K=K1
02800 L=0
02810 GOSUB 08180
02820 GOSUB 07390
02830 W3(K,L)=W5
02840 L=L1
02850 GOSUB 08270
02860 GOSUB 07390
02870 W3(K,L)=W5
02880 REM ---------------METAL MASS POINTS---------------------------
02890 FOR L=0 TO L1
02900 R2(0,L)=R4
02910 R2(K1,L)=R4
02920 NEXT L
02930 FOR K=1 TO K1-1
02940 R2(K,L1)=R4
02950 NEXT K
02960 K=0
02970 L=0
02980 GOSUB 07730
02990 GOSUB 07390
03000 W(1,0)=W(1,0)+W3+W4
03010 FOR L=1 TO L1-1
03020 K=0
03030 GOSUB 07730
03040 GOSUB 07390
03050 W(1,L)=W(1,L)+W3+W4
03060 GOSUB07820
03070 GOSUB 07390
03080 W(1,L)=W(1,L)+W3+W4
03090 NEXT L
03100 K=0
03110 L=L1
03120 GOSUB 07300
03130 GOSUB 07390
03140 W(1,L1)=W(1,L1)+W3+W4
03150 GOSUB 07820
03160 GOSUB 07390
03170 W(1,L1)=W(1,L1)+W3+W4
03180 K=1
03190 GOSUB 08000
03200 GOSUB 07390
03210 W(1,L1)=W(1,L1)+W5
03220 FOR K=2 TO K1-1
03230 L=L1
03240 GOSUB 07910
```

TABLE A-I (CONT.)

```
03250 GOSUB 07390
03260 W(K,L)=W(K,L)+W5
03270 GOSUB 08000
03280 GOSUB 07390
03290 W(K,L)=W(K,L)+W5
03300 NEXT K
03310 K=K1
03320 L=L1
03330 GOSUB 07300
03340 GOSUB 07390
03350 W(K,L)=W(K,L)+W5
03360 GOSUB 07910
03370 GOSUB 07390
03380 W(K,L)=W(K,L)+W5
03390 GOSUB 07820
03400 GOSUB 07390
03410 W(K,L)=W(K,L)+W5
03420 K=K1
03430 FOR L=1 TO L1-1
03440 GOSUB 07730
03450 GOSUB 07390
03460 W(K,L)=W(K,L)+W5
03470 GOSUB 07820
03480 GOSUB 07390
03490 W(K,L)=W(K,L)+W5
03500 NEXT L
03510 L=0
03520 GOSUB 07730
03530 GOSUB07390
03540 W(K,L)=W(K,L)+W5
03550 REM------------SPECIAL BASE END METAL MASSES---------
03560 GOSUB 09110
3570 REM
03610 REM----------PRINT ZONE CENTERS AND MASSES--------
03620 REM----------PUT INPUT PRINT OUT BYPASS HERE---------------------
03630 PRINT"K","L","R1(K,L)","Z1(K,L)","W1(K,L)"
03640 FOR K=1 TO K1-1
03650 FOR L=0 TO L1-1
03660 PRINT K,L,R1(K,L),Z1(K,L),W1(K,L)
03670 NEXT L
03680 NEXT K
03690 PRINT
03700 PRINT "K","L","R(K,L)","Z(K,L)","W(K,L)"
03710 FOR K=1 TO K1
03720 FOR L=0 TO L1
03730 PRINT K,L,R(K,L),Z(K,L),W(K,L)
03740 NEXT L
03750 NEXT K
03760 REM---------------C/M AND SCALE FACTOR-----------------------
03770 PRINT"C/M AND SCALE FACTOR"
03780 PRINT"X=S1*D1**(1/3)/(1+2*C/M)"
03790 PRINT
03800 PRINT"K","Z(K,0)","IR(CM)","C/M","CHI(IN**4/3)"
03810 FOR K=1TO K1
03820 Y4=R3/R4/((R(K,L1+1)/R(K,L1))**2-1)
03830 Y5=(R(K,L1+1)-R(K,L1))*R(K,L1)**(1/3)/(1+2*Y4)*.36355
```

TABLE A-1 (CONT.)

```
03840 PRINT K,Z(K,0),R(K,L1),Y4,Y5
03850 NEXT K
03860 REM-----------INITIALIZE  N,T--------------
03870 N=0
03880 T=(Z1(K4+1,0)-Z(K4+1,0))/D
03890 REM---------------INITIALIZE V1,E2,FOR K=1 TO K4--------------
03900 FOR L=0 TO L1-1
03910 FOR K=1 TO K4
03920 V1(K,L)=1
03930 E2(K,L)=0
03940 NEXT K
03950 REM --------------INITIALIZE V1,E2,FOR K=K4+1 TO K1-1----------
03960 FOR K=K4+1 TO K1-1
03970 V1(K,L)=1
03980 E2(K,L)=E1
03990 NEXT K
04000 NEXT L
04010 REM---------------INITIALIZE J,V---------------------------
04020 FOR K=1 TO K1
04030 FOR L=0 TO L1
04040 J(K,L)=0
04050 V(K,L)=0
04060 NEXT L
04070 NEXT K
4080 REM
04095 REM -------INITIALIZE INTERMEDIATE SLIDE PTS Z4(K),R4(,K)---------
04100 FOR K=2 TO K1
04110 K9(K)=K-1
04120 R4(K)=R(K,L1)
04130 Z4(K)=Z(K,L1)
04140 NEXT K
4145 D1=D1*30.48
04150 REM---------------ENERGY CHECK-------------------------------
04160 GOSUB 11400
04170 REM-----------FLUID DYNAMICS - MAIN ROUTINE
04180 N=N+1
04190 IF T>T4 THEN 11970
04200 IF N>N6 THEN 11970
04210 T=T+T1
04220 REM-----------------K3 FOR LIMITED COMPUTATION-----------------
04230 FOR K=K1-1 TO 1 STEP -1
04240 IF(D*T-Z(K,0)+Z)>0THEN04260
04250 GO TO 04280
04260 K3=K
04270 K=1
04280 NEXT K
04290 K3=K3+5
04300 IF K3>K1-1 THEN  04320
04310 GO TO 04330
04320 K3=K1-1
04330 REM
04340 PRINT"N="N,"T="T,"K3="K3
04350 REM----------------NEW POSITIONS----------------------------
04360 REM-----------R,Z FOR K3<K1-1------------
04370 FOR K=1 TO K3
04380 FOR L=0 TO L1
```

TABLE A-I (CONT.)

```
04390 Z(K,L)=Z(K,L)+T1*U(K,L)
04400 R(K,L)=R(K,L)+T1*V(K,L)
04410 NEXT L
04420 NEXT K
04430 IF K3<K1-1 THEN 04490
04440 REM--------------------R,Z FOR K=K1---------------------------
04450 FOR L=0 TO L1
04460 Z(K1,L)=Z(K1,L)+T1*U(K1,L)
04470 R(K1,L)=R(K1,L)+T1*V(K1,L)
04480 NEXT L
04490 REM
04500 REM--------------NEW POSITIONS OF SLIDE PTS,Z3(K),R3(K)---
04510 GOSUB 10290
04520 REM --------CELL CENTER VARIABLES-------------
04530 FOR K=1 TO K3
04540 FOR L=0 TO L1-1
04550 P=P2(K,L)-Q1(K,L)
04560 V5(K,L)=V1(K,L)
04570 REM---------------CELL CORNERS FOR V1(K,L1-1) CALC------------
04580 IF L=L1-1 THEN 10660
04590 GOSUB 07300
04600 GOSUB 07390
04610 V1(K,L)=(V3+V4)*R2(K,L)/W1(K,L)
04620 A1(K,L)=A3+A4
04630 V6=(V1(K,L)-V5(K,L))
04640 V7=V6/T1
04650 V8=(V1(K,L)+V5(K,L))/2
04660 V9=V7/V8
04670 IF V9>0 THEN 04700
04680 Q1(K,L)=C3*C3*R2(K,L)*(A3+A4)*V9*V9/V8
04690 GO TO 04720
04700 Q1(K,L)=0
04710 REM
04720 REM-------------BURN FRACTION----------------
04730 IF F(K1-1)=1 THEN 04760
04740 IF L=0 THEN 11740
04750 REM-------------EQ OF STATE ROUTINE   CALC P2,E2,C2-------------
04760 GOSUB 08450
04770 REM--------------------------TIME STEP-----------------------
04780 REM----------------TIME STEP FOR EACH CELL,T3(K,L)--------------
04790 IF L=L1-1 THEN 04830
04800 S3=(Z(K+1,L+1)-Z(K,L))**2+(R(K+1,L+1)-R(K,L))**2
04810 S4=(Z(K,L+1)-Z(K+1,L))**2+(R(K,L+1)-R(K+1,L))**2
04820 GO TO 04850
04830 S3=(Z3(K+1)-Z(K,L))**2+(R3(K+1)-R(K,L))**2
04840 S4=(Z3(K)-Z(K+1,L))**2+(R3(K)-R(K+1,L))**2
04850 IF S3<S4 THEN 04880
04860 S5=S4
04870 GO TO 04890
04880 S5=S3
04890 S5=SQR(S5)
04900 IF  V9>0 THEN04930
04910 B=2*C3*S5*V9
04920 GO TO 04940
04930 B=0
04940 T3(K,L)=S5/3/SQR(C2(K,L)+B*B)
```

TABLE A-1 (CONT.)

```
04950 NEXT L
04960 NEXT K
04970 REM--------------------NEW TIME STEPS T1,T2--------------------
04980 T6=T1
04990 T5=T3(1,0)
05000 FOR K=1 TO K3
05010 FOR L=0 TO L1-1
05020 IF T3(K,L)-T5<0 THEN 05040
05030 GO TO 05050
05040 T5=T3(K,L)
05050 NEXT L
05060 NEXT K
05070 IF T5>E8*T1 THEN 05100
05080 T1=T5
05090 GO TO 05110
05100 T1=E8*T6
05110 T2=(T1+T6)/2
05120 REM---------------------R4,Z4 FOR SLIDING----------------------
05130 GO TO 11090
05140 REM-----------------VELOCITY OF INTERIOR POINTS-----------------
05150 FOR K=2 TO K3
05160 FOR L=1 TO L1-1
05170 REM--------------------CYCLONE ACCEL FORMULAS-------------------
05180 GO TO 10830
05350 NEXT L
05360 NEXT K
05370 REM---------------VELOCITY OF AXIS INTERIOR POINTS--------------
05380 FOR K=2 TO K1
05390 R1(K-1,0)=(R(K-1,0)+R(K,0)+R(K,1)+R(K-1,1))/4
05400 Z1(K-1,0)=(Z(K-1,0)+Z(K,0)+Z(K,1)+Z(K-1,1))/4
05410 NEXT K
05420 L=0
05430 FOR K=2 TO K1-1
05440 GOSUB 08090
05450 GOSUB 07390
05460 B1=V3+V4
05470 GOSUB 08180
05480 GOSUB 07390
05490 B1=B1+V3+V4
05500 B2=Z(K+1,L)-Z(K-1,L)
05510 U(K,0)=U(K,0)-T2*B1*2*(P2(K,L)-P2(K-1,L))/W(K,L)/B2
05520 V(K,0)=0
05530 NEXT K
05540 REM---------------VELOCITY OF METAL MASS POINTS-----------------
05550 REM---------------------U(1,0),V(1,0)---------------------------
05560 B1=R(1,1)/2
05570 U(1,0)=U(1,0)-T2*B1*B1*(3*P2(1,0)-P2(2,0))/4/W(1,0)
05580 V(1,0)=0
05590 REM-----------------U,V FOR K=1,L=1 TO L1-1---------------------
05600 K=1
05610 FOR L=1 TO L1-1
05620 P4=(P2(K,L)+P2(K,L-1))/2
05630 P3=(P2(K+1,L)+P2(K+1,L-1))/2
05640 P5=(3*P4-P3)/2
05650 B1=(R(K,L)+R(K,L-1))**2/4
05660 B2=(R(K,L)+R(K,L+1))**2/4
```

TABLE A-I (CONT.)

```
05670 B3=(3*R(K,L)+R(K,L-1))*(Z(K,L)-Z(K,L-1))/8
05680 B4=(3*R(K,L)+R(K,L+1))*(Z(K,L+1)-Z(K,L))/8
05690 U(K,L)=U(K,L)-T2*(B2-B1)*P5/2/W(K,L)
05700 V(K,L)=V(K,L)+T2*(B3+B4)*P5/W(K,L)
05710 NEXT L
05720 REM--------------------U,V FOR K=1,L=L1-----------------------
05730 K=1
05740 L=L1
05750 B3=(R(K,L)+R(K,L-1))**2/4
05760 B4=(R(K,L)+R(K+1,L))**2/4
05770 B5=T2/2/W(K,L)
05780 U(K,L)=U(K,L)+B5*(B3-B4)*P2(1,L1-1)
05790 B3=(3*R(K,L)+R(K+1,L))*(Z(K+1,L)-Z(K,L))/8
05800 B4=(3*R(K,L)+R(K,L-1))*(Z(K,L)-Z(K,L-1))/8
05810 V(1,L1)=V(1,L1)+T2*(B3+B4)*P2(1,L1-1)/W(K,L)
05820 REM-----------------------P3(1)  ,P3(K3+1)--------------------
05830 P3(1)=P2(1,L1-1)
05840 P3(K3+1)=P2(K3,L1-1)
05850 REM-------------------U,V FOR L=L1,K=2 TO K3------------------
05860 REM-----EXTRAPOLATION FOR P3(K) AT SLIDE PTS---------
05870 L=L1
05880 FOR K=2 TO K3
05890 P4=(P2(K,L-1)+P2(K-1,L-1))/2
05900 P3=(P2(K,L-2)+P2(K-1,L-2))/2
05910 P5=P4+(P4-P3)/2
05920 P3(K)=P5
05930 NEXT K
05940 FOR K=2 TO K3
05950 J=1
05960 D5=SGN(Z(K,L1)+S8(J)*R(K,L1)-S8(J)*R(J,L1-1)-Z(J,L1-1))
05970 D6=SGN(Z(K,L1)+S8(J+1)*R(K,L1)-S8(J+1)*R(J+1,L1-1)-Z(J+1,L1-1))
05980 IF D5<>D6 THEN 06050
05990 D5=D6
06000 J=J+1
06010 IF J>K1-1 THEN 06030
06020 GO TO 05970
06030 GO TO 09750
06040 GO TO 11970
06050 D7=SQR((Z(K,L)-Z3(J))**2+(R(K,L)-R3(J))**2)
06060 D8=SQR((Z(K,L)-Z3(J+1))**2+(R(K,L)-R3(J+1))**2)
06070 P5=P3(J)+D7*(P3(J+1)-P3(J))/(D7+D8)
06080 B3=(R(K-1,L)+R(K,L))**2
06090 B4=(R(K+1,L)+R(K,L))**2
06100 B5=T2/8/W(K,L)
06110 U(K,L)=U(K,L)+B5*(B3-B4)*P5
06120 REM
06130 REM
06140 B3=(Z(K,L)-Z(K-1,L))/2
06150 B4=(Z(K+1,L)-Z(K,L))/2
06160 B5=(3*R(K,L)+R(K-1,L))/4
06170 B6=(3*R(K,L)+R(K+1,L))/4
06180 B7=(B3*B5+B4*B6)*T2/W(K,L)
06190 V(K,L)=V(K,L)+B7*P5
06200 NEXT K
06210 IF K3=K1-1 THEN 06230
06220 GO TO 06250
```

TABLE A-I (CONT.)

```
06230 REM
06240 REM--------------------U,V FOR K=K1,L=0------------------------
06250 K=K1
06260 L=0
06270 B1=R(K,1)/2
06280 REM
06290 P5=(3*P2(K1-1,0)-P2(K1-2,0))/2
06300 U(K,L)=U(K,L)+T2*B1*B1*P5/2/W(K,L)
06310 V(K,L)=0
06320 REM---------------------U,V FOR K=K1,L=1 TO L1-1----------------
06330 FOR L=1 TO L1-1
06340 B2=(R(K,L)+R(K,L+1))**2/4
06350 B3=(R(K,L)+R(K,L-1))**2/4
06360 P4=(P2(K-1,L)+P2(K-1,L-1))/2
06370 P3=(P2(K-2,L)+P2(K-2,L-1))/2
06380 B5=(3*P4-P3)/2
06390 U(K,L)=U(K,L)+(B2-B3)*T2*B5/W(K,L)/2
06400 B3=(3*R(K,L)+R(K,L+1))*(Z(K,L)-Z(K,L+1))/8
06410 B4=(3*R(K,L)+R(K,L-1))*(Z(K,L-1)-Z(K,L))/8
06420 V(K,L)=V(K,L)+(B3+B4)*B5*T2/W(K,L)
06430 NEXT L
06440 REM------------------------U,V FOR K=K1,L=L1------------------
06450 L=L1
06460 B3=(R(K-1,L)+R(K,L))**2/4
06470 B4=(R(K,L)+R(K,L-1))**2/4
06480 B5=T2/2/W(K,L)
06490 U(K,L)=U(K,L)+(B3-B4)*P2(K-1,L-1)*B5
06500 B3=(3*R(K,L)+R(K-1,L))*(Z(K,L)-Z(K-1,L))/8
06510 B4=(3*R(K,L)+R(K,L-1))*(Z(K,L-1)-Z(K,L))/8
06520 V(K,L)=V(K,L)+(B3+B4)*P2(K-1,L-1)*T2/W(K,L)
06530 REM
06540 REM
06550 REM-------------------FLOW VARIABLE PRINT ROUTINE---------------
06560 IF N=1 THEN 06590
06570 IF T>=T7*N7 THEN 06590
06580 GO TO 07130
06590 IF N<N4 THEN 06610
6600  GOSUB 20020
06610 PRINT ≡N=≡N,≡T=≡T,≡T1=≡T1,≡T2=≡T2
06620 PRINT
06630 REM  FOR FLOW VARIABLE PRINT BYPASS
06640 REM---------GO TO END OF FLOW VARIABLE ROUTINE-----
06650 REM
06660 FOR K=1 TO K3
06670 PRINT≡K=≡K,≡F(K)=≡F(K),≡MVEL=≡SQR(U(K,L1)**2+V(K,L1)**2)*32808
06680 PRINT≡L≡,≡Z≡,≡R≡,≡U≡,≡V≡
06690 FOR L=0 TO L1
06700 PRINT L,Z(K,L),R(K,L),U(K,L),V(K,L)
06710 NEXT L
06720 PRINT
06730 PRINT≡L≡,≡P1+Q1≡,≡Q1≡,≡V1≡,≡E2≡
06740 FOR L=0 TO L1-1
06750 PRINT L,P2(K,L),Q1(K,L),V1(K,L),E2(K,L)
06760 NEXT L
06770 PRINT≡K≡,≡L≡,≡T3(K,L)≡,≡C2(K,L)≡
06780 FOR L=0TO L1-1
```

TABLE A-I (CONT.)

```
06790 PRINTK,L,T3(K,L),C2(K,L)
06800 NEXTL
06810 NEXT K
06820 IF K3<>K1-1 THEN 06920
06830 K=K1
06840 PRINT≡K=≡K
06850 PRINT≡L≡,≡Z≡,≡R≡,≡J≡,≡V≡
06860 FOR L=0 TO L1
06870 PRINT L,Z(K,L),R(K,L),J(K,L),V(K,L)
06880 NEXT L
06890 PRINT
06900 PRINT
06910 PRINT
06920 PRINT≡K≡,≡R3≡,≡Z3≡,≡P3≡
06930 FOR K=1 TO K3+1
06940 PRINT K,R3(K),Z3(K),P3(K)
06950 NEXT K
06960 PRINT
06970 PRINT≡K≡,≡L≡,≡VEL(FT/SEC)≡
06980 K=1
06990 GOSUB 11920
07000 IF K3<K1-1 THEN 07030
07010 K=K1
07020 GOSUB 11920
07030 REM
07040 PRINT ≡K≡,≡K9(K)≡,≡R4(K)≡,≡Z4(K)≡,≡S8(K)≡
07050 FOR K=1TO K3+1
07060 PRINT K,K9(K),R4(K),Z4(K)          ,S8(K)
07070 NEXT K
07080 REM ------------END OF FLOW VARIABLE PRINT ROUTINE--------------
07090 IF N=1 THEN 07130
07100 N7=N7+1
07110 IF N7>=N5 THEN 11970
07120 REM--------------------------ENERGY CHECK----------------------
07130 GOSUB 11400
07140 REM-----------RETURN TO START OF MAIN ROUTINE-------------------
07150 REM
07160 GO TO 04180
07170 REM
07180 REM
7190 REM ----------INITIALIZE HE AND FUZE CELL DENSITIES---------------
07200 FOR L=0 TO L1
07210 FOR K=1 TO K4
07220 R2(K,L)=R2
07230 NEXT K
07240 FOR K=K4+1 TO K1
07250 R2(K,L)=R3
07260 NEXT K
07270 NEXT L
07280 RETURN
07290 REM---------------SUBROUTINES FOR MASS,VOLUME,AREA---------------
07300 G1=Z(K,L)
07310 H1=R(K,L)
07320 G2=Z(K+1,L)
07330 H2=R(K+1,L)
07340 G3=Z(K+1,L+1)
```

TABLE A-1 (CONT.)

```
07350 H3=R(K+1,L+1)
07360 G4=Z(K,L+1)
07370 H4=R(K,L+1)
07380 RETURN
07390 X1=G1
07400 Y1=H1
07410 X2=G2
07420 Y2=H2
07430 IF K<K1/2 THEN 07470
07440 X3=G3
07450 Y3=H3
07460 GO TO 07490
07470 X3=G4
07480 Y3=H4
07490 GOSUB 07650
07500 V3=V2
07510 A3=A
07520 W3=W
07530 IF K<K1/2 THEN 07570
07540 X2=G4
07550 Y2=H4
07560 GO TO 07590
07570 X1=G3
07580 Y1=H3
07590 GOSUB 07650
07600 V4=V2
07610 A4=A
07620 W4=W
07630 W5=W3+W4
07640 RETURN
07650 A6 =X1*Y2-X2*Y1
07660 A7=X2*Y3-X3*Y2
07670 A8=X3*Y1-X1*Y3
07680 A=ABS(A6+A7+A8)/2
07690 R=(Y1+Y2+Y3)/3
07700 V2=A*R
07710 W=V2*H2(K,L)
07720 RETURN
07730 G1=Z(K,L)
07740 H1=R(K,L)
07750 G2=Z(K+1,L)
07760 H2=R(K+1,L)
07770 G3=(Z(K+1,L+1)+G2)/2
07780 H3=(R(K+1,L+1)+H2)/2
07790 G4=(Z(K,L+1)+G1)/2
07800 H4=(R(K,L+1)+H1)/2
07810 RETURN
07820 G1=Z(K,L)
07830 H1=R(K,L)
07840 G2=Z(K+1,L)
07850 H2=R(K+1,L)
07860 G3=(Z(K+1,L-1)+G2)/2
07870 H3=(R(K+1,L-1)+H2)/2
07880 G4=(Z(K,L-1)+G1)/2
07890 H4=(R(K,L-1)+H1)/2
07900 RETURN
```

TABLE A-1 (CONT.)

```
07910 G1=Z(K,L)
07920 H1=R(K,L)
07930 G2=Z(K,L+1)
07940 H2=R(K,L+1)
07950 G3=(Z(K-1,L+1)+G2)/2
07960 H3=(R(K-1,L+1)+H2)/2
07970 G4=(Z(K-1,L)+G1)/2
07980 H4=(R(K-1,L)+H1)/2
07990 RETURN
08000 G1=Z(K,L)
08010 H1=R(K,L)
08020 G2=Z(K,L+1)
08030 H2=R(K,L+1)
08040 G3=(Z(K+1,L+1)+G2)/2
08050 H3=(R(K+1,L+1)+H2)/2
08060 G4=(Z(K+1,L)+G1)/2
08070 H4=(R(K+1,L)+H1)/2
08080 RETURN
08090 G1=Z(K,L)
08100 H1=R(K,L)
08110 G2=(Z(K+1,L)+G1)/2
08120 H2=(R(K+1,L)+H1)/2
08130 G3=Z1(K,L)
08140 H3=R1(K,L)
08150 G4=(Z(K,L+1)+G1)/2
08160 H4=(R(K,L+1)+H1)/2
08170 RETURN
08180 G1=Z(K,L)
08190 H1=R(K,L)
08200 G2=(Z(K,L+1)+G1)/2
08210 H2=(R(K,L+1)+H1)/2
08220 G3=Z1(K-1,L)
08230 H3=R1(K-1,L)
08240 G4=(Z(K-1,L)+G1)/2
08250 H4=(R(K-1,L)+H1)/2
08260 RETURN
08270 G1=Z(K,L)
08280 H1=R(K,L)
08290 G2=(Z(K,L-1)+G1)/2
08300 H2=(R(K,L-1)+H1)/2
08310 G3=Z1(K-1,L-1)
08320 H3=R1(K-1,L-1)
08330 G4=(Z(K-1,L)+G1)/2
08340 H4=(R(K-1,L)+H1)/2
08350 RETURN
08360 G1 =Z(K,L)
08370 H1=R(K,L)
08380 G2=(Z(K,L-1)+G1)/2
08390 H2=(R(K,L-1)+H1)/2
08400 G3=Z1(K,L-1)
08410 H3=R1(K,L-1)
08420 G4=(Z(K+1,L)+G1)/2
08430 H4=(R(K+1,L)+H1)/2
08440 RETURN
08450 REM    ---------EQ OF STATE ROUTINE   CALC P2,E2,C2---------------
08460 IF N>0 THEN 08490
```

TABLE A-I (CONT.)

```
08470 GOSUB 08760
08480 GO TO 08750
08490 IF K<=K4 THEN 10150
08500 N2=0
08510 H=V1(K,L)
08520 C4=D2/H
08530 C5=D3*(1-C4/F1)*EXP(-F1*H)+D4*(1-C4/F2)*EXP(-F2*H)
08540 E6=E2(K,L)
08550 FOR N2=0 TO 1
08560 P1=C4*E2(K,L)+C5
08570 P1=P1*F(K)
08580 P3=P1+Q1(K,L)
08590 E2(K,L)=E6-((P+P1)/2+Q1(K,L))*V6
08610 NEXT N2
08620 P2(K,L)=P3
08630 F3=-D2/H/H
08640 F4=-D3*(F3/F1+F1*(1-C4/F1))*EXP(-F1*H)
08650 F4=F4-D4*(F3/F2+F2*(1-C4/F2))*EXP(-F2*H)
08660 C2(K,L)=-(H*H/R2(K,L))*(-P1*C4+E2(K,L)*F3+F4)
08670 IF C2(K,L)>0 THEN 08750
08680 PRINT"N="N,"K="K,"L="L,"P1="P1,"V1(K,L)="V1(K,L)
08690 PRINT"E2(K,L)="E2(K,L),"E6="E6
08700 PRINT"R(K,L)="R(K,L),"Z(K,L)="Z(K,L)
08710 PRINT"R(K+1,L)="R(K+1,L),"Z(K+1,L)="Z(K+1,L)
08720 PRINT"R(K+1,L+1)="R(K+1,L+1),"Z(K+1,L+1)="Z(K+1,L+1)
08730 PRINT"R(K,L+1)="R(K,L+1),"Z(K,L+1)="Z(K,L+1)
08740 PRINT"R3(K)="R3(K),"Z3(K)="Z3(K)
08750 RETURN
08760 D=.7839
08770 D2=.30
08780 R3=1.634
08790 D3=4.9055
08800 D4=.058
08810 E1=.0814
08820 F1=4.2
08830 F2=0.9
08840 Q3=1-0.731304
08850 PRINT"JWL EQN"
08860 PRINT"D="D,"RHO(0)="R3,"D2="D2,"D3="D3,"D4="D4
08870 PRINT"E1="E1"(MBAR-CC/CC)","F1="F1,"F2="F2
08880 PRINT "Q3=1-V1(CJ)="Q3
08890 PRINT
08900 RETURN
08910 REM-------BASE CORNER MASS CHANGE-----------
08920 X1=(Z(K1-1,L1)+Z(K1,L1))/2
08930 Y1=(R(K1-1,L1)+R(K1,L1))/2
08940 X2=X1
08950 Y2=(R(K1-1,L1+1)+R(K1,L1+1))/2
08960 X3=(X1+Z(K1+1,L1+1))/2
08970 Y3=(Y2+R(K1+1,L1+1))/2
08980 GOSUB 07650
08990 W(K1-1,L1)=W(K1-1,L1)+W
09000 W(K1,L1)=W(K1,L1)-W
09010 X1=(Z(K1,L1)+Z(K1,L1-1))/2
09020 Y1=(R(K1,L1)+R(K1,L1-1))/2
09030 X2=(Z(K1+1,L1)+Z(K1+1,L1-1))/2
```

TABLE A-I (CONT.)

```
09040 Y2=(R(K1+1,L1)+R(K1+1,L1-1))/2
09050 X3=(X2+Z(K1+1,L1+1))/2
09060 Y3=(Y2+R(K1+1,L1+1))/2
09070 GOSUB 07850
09080 W(K1,L1-1)=W(K1,L1-1)+W
09090 W(K1,L1)=W(K1,L1)-W
09100 RETURN
09110 REM-----------BASE END MASSES-105 MM-----------
09120 K=K1
09130 L=1
09140 GOSUB 07820
09150 GOSUB 07390
09160 W(K,L)=W5
09170 GOSUB 07730
09180 G3=36.9
09190 H3=2.37
09200 GOSUB 07390
09210 W(K,L)=W(K,L)+W5
09220 L=2
09230 G1=Z(K,L)
09240 H1=R(K,L)
09250 G2=36.9
09260 H2=3.25
09270 GOSUB 07390
09280 W(K,L)=W5
09290 G4=(Z(K,L)+Z(K,L+1))/2
09300 H4=(R(K,L)+R(K,L+1))/2
09310 G3=36.9
09320 H3=4.30
09330 GOSUB 07390
09340 W(K,L)=W(K,L)+W5
09350 L=3
09360 G1=Z(K,L)
09370 H1=R(K,L)
09380 G2=36.9
09390 H2=4.55
09400 GOSUB 07390
09410 W(K,L)=W5
09420 G4=33.35
09430 H4=2.8
09440 G3=34.55
09450 H3=4.95
09460 GOSUB 07390
09470 W(K,L)=W(K,L)+W5
09480 K=K1-1
09490 L=L1
09500 G1=Z(K,L)
09510 H1=R(K,L)
09520 G2=32.9
09530 H2=5.2
09540 GOSUB 07390
09550 W(K,L)=W5
09560 G4=32.2
09570 H4=3.15
09580 G3=32.5
09590 H3=5.25
```

TABLE A-1 (CONT.)

```
09600 GOSUB 07390
09610 W(K,L)=W(K,L)+W5
09620 K=K1-2
09630 L=L1
09640 G1=Z(K,L)
09650 H1=R(K,L)
09660 G2=Z(K,L+1)
09670 H2=R(K,L+1)
09680 GOSUB 07390
09690 W(K,L)=W5
09700 GOSUB 07910
09710 GOSUB 07390
09720 W(K,L)=W(K,L)+W5
09730 RETURN
09740 REM---EXIT IF J>K1-1 IN MASS PT PRESSURE ROUTINE----
09750 PRINT"BDRY PRESSURE ROUTINE"
09760 PRINT"J="J,"K="K,"R(K,L1)="R(K,L1),"Z(K,L1)="Z(K,L1)
09770 PRINT "J","SB(J)","R(J,L1-1)","Z(J,L1-1)","D6"
09780 FOR J=1 TO K1
09790 D6=Z(K,L1)+SB(J)*R(K,L1)-SB(J)*R(J,L1-1)-Z(J,L1-1)
09800 PRINTJ,SB(J),R(J,L1-1),Z(J,L1-1),D6
09810 NEXT J
09820 GO TO 11970
09830 REM------------TEMP P,E ITERATION(ALT METHOD)--------
09840 F5=F(K)
09850 E6=E2(K,L)-(P+Q1(K,L))*V5
09860 P3=(C4*E6+C5)*F5
09870 E2(K,L)=E6-.5*(P3-P)*V6
09880 P1=(C4*E2(K,L)+C5)*F5
09890 P2(K,L)=P1+Q1(K,L)
09900 GO TO 08630
09910 REM-------------------INPUT R(K,L1),R(K,L1+1) STEP 1--------------
09920  FOR K=0 TO K1+1
09930 READ R(K,L1),R(K,L1+1)
09940 NEXT K
09950 RETURN
09960 REM ---------------INPUT R(K,L1),R(K,L1+1) STEP 2-----------------
09970 READ R(0,L1),R(0,L1+1)
09980 FOR K=1 TO K1 STEP 2
09990 READ R(K,L1),R(K,L1+1)
10000 NEXT K
10010 READ R(K1+1,L1),R(K1+1,L1+1)
10020 FOR K=2 TO K1-1 STEP2
10030 R(K,L1)=(R(K+1,L1)+R(K-1,L1))/2
10040 R(K,L1+1)=(R(K+1,L1+1)+R(K-1,L1+1))/2
10050 NEXT K
10060 RETURN
10070 REM---------INPUT SPECIAL R(K,L1),R(K,L1+1) VALUES----------------
10080 R(20,L1)=3.05
10090 R(20,L1+1)=5.2
10100 R(21,L1)=2.55
10110 R(21,L1+1)=5.05
10120 R(22,L1)=R(21,L1)
10130 RETURN
10140 REM------EQ OF STATE FOR FUZE CELLS-------------
10150 P3=P2(K,L)
```

TABLE A-I (CONT.)

```
10160 P2(K,L)=.01/(V1(K,L)**7)+Q1(K,L)
10170 E2(K,L)=E2(K,L)-((P3+P2(K,L))/2)*V6
10180 C2(K,L)=.07/R2(K,L)/(V1(K,L)**6)
10190 GO TO 08670
10200 REM------------------------SLIDE ROUTINE----------------------
10210 L=L1-1
10220 IF N>1 THEN 10310
10230 FOR K=1 TO K3+1
10240 R3(K)=R(K,L1)
10250 Z3(K)=Z(K,L1)
10260 NEXT K
10270 GO TO 10650
10280 REM
10290 REM
10300 REM
10310 FOR K=2 TO K3
10320 REM
10330 REM
10340 REM
10350 S8(K)=-(Z4(K)-Z(K,L))/(R4(K)-R(K,L))
10360 REM
10370 J=1
10380 D5=Z(J,L1)+(R(J,L1)-R(K,L))*S8(K)-Z(K,L)
10390 D6=Z(J+1,L1)+(R(J+1,L1)-R(K,L))*S8(K)-Z(K,L)
10400 IF D6=0 THEN 10540
10410 IF SGN(D6)<>SGN(D5) THEN 10460
10420 J=J+1
10430 IF J=K1 THEN 10520
10440 D5=D6
10450 GO TO 10390
10460 S7=(R(J+1,L1)-R(J,L1))/(Z(J+1,L1)-Z(J,L1))
10470 Z3(K)=Z(K,L)+S8(K)*S7*Z(J,L1)-S8(K)*(R(J,L1)-R(K,L))
10480 Z3(K)=Z3(K)/(1+S8(K)*S7)
10490 R3(K)=R(J,L1)-S7*Z(J,L1)+S7*Z3(K)
10500 K9(K)=J
10510 GO TO 10570
10520 PRINT"SLIDE ROUTINE,J="J,"K="K
10530 GO TO 11970
10540 R3(K)=R(J+1,L1)
10550 Z3(K)=Z(J+1,L1)
10560 K9(K)=J
10570 REM
10580 NEXT K
10590 R3(1)=R(1,L1)
10600 Z3(1)=Z(1,L1)
10610 R3(K3+1)=R(K3+1,L1)
10620 Z3(K3+1)=Z(K3+1,L1)
10630 S8(1)=1
10640 S8(K1)=-1
10650 RETURN
10660 REM ---------CELL CORNERS FOR L=L1-1----------
10670 G1=Z(K,L)
10680 H1=R(K,L)
10690 G2=Z(K+1,L)
10700 H2=R(K+1,L)
10710 G3=Z3(K+1)
```

TABLE A-I (CONT.)

```
10720 H3=R3(K+1)
10730 G4=Z3(K)
10740 H4=R3(K)
10750 GO TO 04600
10760 REM
10770 REM
10780 REM
10790 REM
10800 REM
10810 REM
10820 REM--------------CYCLONE ACCEL FORMULAS-----------
10830 H1=(P2(K,L)+P2(K,L-1)-P2(K-1,L)-P2(K-1,L-1))/2
10840 H2=(P2(K,L)+P2(K-1,L)-P2(K-1,L-1)-P2(K,L-1))/2
10850 B1=(R(K+1,L)-R(K-1,L))/2
10860 IF L<L1 [illegible] THEN 10900
10870 B2=(R[illegible](K,L-1))/2
10880 B4=(Z3[illegible],L-1))/2
10890 GO TO 109[illegible]
10900 B2=(R(K,L+1)-R(K,L-1))/2
10910 B4=(Z(K,L+1)-Z(K,L-1))/2
10920 B3=(Z(K+1,L)-Z(K-1,L))/2
10930 B4=(Z(K,L+1)-Z(K,L-1))/2
10940 B5=T2*R(K,L)/W(K,L)
11000 U(K,L)=U(K,L)+B5*(B1*H2-B2*H1)
11010 V(K,L)=V(K,L)+B5*(B4*H1-B3*H2)
11020 GO TO 05350
11030 REM------------INITIALIZE SLIDE PTS,Z3(K),R3(K)--------
11040 FOR K=1 TO K1
11050 R3(K)=R(K,L1)
11060 Z3(K)=Z(K,L1)
11070 NEXT K
11080 RETURN
11090 REM-------------CALC R4,Z4 FOR SLIDING---------
11100 IF K9(K3)=0 THEN 11120
11110 GO TO 11130
11120 K9(K3)=K3-1
11130 FOR K=2 TO K3
11140 R8=R(K9(K),L1)
11150 Z8=Z(K9(K),L1)
11160 R9=R(K9(K)+1,L1)
11170 Z9=Z(K9(K)+1,L1)
11180 D9=SQR((Z9-Z8)**2+(R9-R8)**2)
11190 S9=(R9-R8)/D9
11200 C9=(Z9-Z8)/D9
11210 G5=P2(K,L1-1)-P2(K-1,L1-1)
11220 G6=Z3(K)-Z(K,L1-1)
11230 G7=R3(K)-R(K,L1-1)
11240 G8=R3(K)/2/W3(K,L1)
11250 G9=G8*G5*(G6*S9-G7*C9)
11260 GO TO 11340
11270 G5=P2(K-1,L1-1)*(R3(K-1)-R(K,L1-1))
11280 G6=P2(K,L1-1)*(R(K,L1-1)-R3(K+1))
11290 G7=P2(K-1,L1-1)*(Z3(K-1)-Z(K,L1-1))
11300 G8=P2(K,L1-1)*(Z(K,L1-1)-Z3(K+1))
11310 REM
11320 F9=R3*(A1(K-1,L1-1)/V1(K-1,L1-1)+A1(K,L1-1)/V1(K,L1-1))/4
```

TABLE A-I (CONT.)

```
11330 G9=G9/2/F9
11340 U7(K)=U(K,L1-1)+T2*C9*G9
11350 V7(K)=V(K,L1-1)+T2*S9*G9
11360 Z4(K)=Z3(K)+U7(K)*T1
11370 R4(K)=R3(K)+V7(K)*T1
11380 NEXT K
11390 GO TO 05140
11400 REM ----------------------ENERGY CHECK----------------------
11410 E3=0
11420 E4=0
11430 E5=0
11440 FOR K=1 TO K1-1
11450 FOR L=0 TO L1-1
11460 E3=E3+E2(K,L)*2*P9*W1(K,L)/R2(K,L)
11470 NEXT L
11480 NEXT K
11490 FOR K=2 TO K3
11500 FOR L=0 TO L1-1
11510 E4=E4+P9*W(K,L)*(U(K,L)**2+V(K,L)**2)
11520 NEXT L
11530 NEXT K
11540 K=1
11550 FOR L=0 TO L1-1
11560 GOSUB 11710
11570 NEXT L
11580 L=L1
11590 FOR K=1 TO K3
11600 E4=E4+P9*W3(K,L)*(U7(K)**2+V7(K)**2)
11610 E5=E5+P9*W(K,L)*(U(K,L)**2+V(K,L)**2)
11620 NEXT K
11630 IF K3<K1-1 THEN 11680
11640 K=K1
11650 FOR L=0 TO L1
11660 GOSUB 11710
11670 NEXT L
11680 E=E3+E4+E5
11690 PRINT≡N=≡N,≡IEGAS=≡E3,≡KEGAS=≡E4,≡KEMET=≡E5,≡ETOT=≡E
11700 RETURN
11710 E4=E4+P9*W3(K,L)*(U(K,L)**2+V(K,L)**2)
11720 E5=E5+P9*W(K,L)*(U(K,L)**2+V(K,L)**2)
11730 RETURN
11740 REM-------BURN FRACTION (PLANE DETONATION)-------
11750 IF F(K)=1 THEN 11900
11760 IF D*T<(Z(K,0)-Z) THEN 11890
11770 IF K=K4+1 THEN 11970
11780 F(K)=(D*T-Z(K,0)+Z)/(Z(K+1,L1)-Z(K,0))
11790 F(K)=F(K)/1.5
11800 Q4=(1-V1(K,0))/Q3
11810 IF F(K)<Q4 THEN 11830
11820 GO TO 11840
11830 F(K)=Q4
11840 IF F(K)>1 THEN 11870
11850 IF F(K)<0 THEN 11890
11860 GO TO 11900
11870 F(K)=1
11880 GO TO 11900
```

TABLE A-1 (CONT.)

```
11890 F(K)=0
11900 REM
11910 GO TO 04760
11920 REM-----CALC MASS PT VEL FOR K=1,K=K1---------------
11930 FOR L=0 TO L1-1
11940 PRINT K,L,SQR(J(K,L)**2+V(K,L)**2)*32808
11950 NEXT L
11960 RETURN
11970 GO TO 30000
20000 REM------------FRAGMENT PREDICTION SCHEME----------
20010 REM
20020 REM------------------------WEIGHT PER POLAR ZONE-----------------
20040 REM-----------SET W7(J2,M5)=0
20050 FOR J2=1 TO 37
20060 FOR M5=1 TO 2*L1+K1
20070 W7(J2,M5)=0
20080 NEXT M5
20090 NEXT J2
20100 REM --------------ANGLE A9(M5+1/2)---------------
20110 PRINT≡M5≡ ≡K≡,≡L≡,≡W5≡,≡A9(M5+1/2)≡
20120 REM
20130 REM
20140 REM
20150 REM
20160 REM
20170 FOR M5=1 TO L1
20180 K=1
20190 L=M5-1
20200 R5=(R(K,L)+R(K,L+1))/2
20210 Z5=(Z(K,L)+Z(K,L+1))/2
20220 U5=U(K,L+1)
20230 V5=V(K,L+1)
20240 Q3(M5)=SQR(U(K,L)**2+V(K,L)**2)
20250 GOSUB 21390
20260 NEXT M5
20270 FOR M5=L1+1 TO L1+K1-1
20280 L=L1
20290 K=M5-L1
20300 R5=(R(K,L)+R(K+1,L))/2
20310 Z5=(Z(K,L)+Z(K+1,L))/2
20320 U5=U(K+1,L)
20330 V5=V(K+1,L)
20340 Q3(M5)=SQR(U(K,L)**2+V(K,L)**2)
20350 GOSUB 21390
20360 NEXT M5
20370 FOR M5=L1+K1 TO L1*2+K1-1
20380 K=K1
20390 L=2*L1+K1-M5
20400 R5=(R(K,L)+R(K,L-1))/2
20410 Z5=(Z(K,L)+Z(K,L-1))/2
20420 U5=U(K,L-1)
20430 V5=V(K,L-1)
20440 Q3(M5)=SQR(U(K,L)**2+V(K,L)**2)
20450 GOSUB 21390
20460 NEXT M5
20470 A9(0)=0
```

TABLE A-I (CONT.)

```
20480 W6(2*L1+K1)=W(K1,0)
20490 Q3(2*L1+K1)=SQR(U(K1,0)**2+V(K1,0)**2)
20500 A9(2*L1+K1)=180
20510 REM-----------------SET N7,W5,M6,Q6,N3,N8=ZERO-----------------
20520 FOR J6=1 TO 37
20530 FOR J=1 TO J9
20540 N7(J6,J)=0
20550 W5(J6,J)=0
20560 M6(J6,J)=0
20570 Q6(J6,J)=0
20580 N3(J6,J)=0
20590 NEXT J
20600 N8(J6)=0
20610 NEXT J6
20620 PRINT
20630 PRINT"MASS PT","POLAR ZONE","WT IN ZONE(GRAINS)"
20640 REM--------------TOTAL FRAG WT AND AVE. VEL IN POLAR ZONES-------
20650 FOR M5=1 TO 2*L1+K1
20660 IF A9(M5-1)>A9(M5) THEN 20700
20670 C7=A9(M5-1)
20680 C8=A9(M5)
20690 GO TO 20720
20700 C7=A9(M5)
20710 C8=A9(M5-1)
20720 J2=INT(C7/5)+1
20730 J3=INT(C8/5)+1
20740 IF J2=J3 THEN 20830
20750 J4=J3-J2-1
20760 B6=C8-C7
20770 W7(J2,M5)=(J2*5-C7)*W6(M5)/B6
20780 W7(J3,M5)=(C8-(J3-1)*5)*W6(M5)/B6
20790 FOR N9=1 TO J4
20800 W7(J2+N9,M5)=5*W6(M5)/B6
20810 NEXT N9
20820 GO TO 20840
20830 W7(J2,M5)=W6(M5)
20840 FOR J6=J2 TO J3
20850 FOR J=1 TO J9
20860 N7(J6,J)=N7(J6,J)+N(M5,J)*W7(J6,M5)*P6
20870 W5(J6,J)=W5(J6,J)+W2(M5,J)*W7(J6,M5)
20880 NEXT J
20890 PRINT M5,J6,W7(J6,M5)*Q9
20900 NEXT J6
20910 NEXT M5
20920 REM -----------------------TOTAL WEIGHT----------------------
20930 T8=0
20940 FOR M5=1 TO 2*L1+K1
20950 T8=T8+W6(M5)
20960 NEXT M5
20970 T9=T8*P8
20980 PRINT
20990 PRINT"TOT METAL WT="T9"LB("T9*7000"GRAINS)"
21000 PRINT
21010 PRINT"POLAR ZONE","MET WT","PCT BY WT","AV VEL"
21020 FOR J2=1 TO 36
21030 W8(J2)=0
```

TABLE A-I (CONT.)

```
21040 W9(J2)=0
21050 FOR M5=1 TO 2*L1+K1
21060 W8(J2)=W8(J2)+W7(J2,M5)
21070 W9(J2)=W9(J2)+W7(J2,M5)*Q3(M5)
21080 IF J2<>36 THEN 21110
21090 W8(J2)=W8(J2)+W7(37,M5)
21100 W9(J2)=W9(J2)+W7(37,M5)*Q3(M5)
21110 NEXT M5
21120 Y(J2)=W9(J2)*32808/W8(J2)
21130 PRINT J2,W8(J2)*Q9,W8(J2)*Q9/T9/70,Y(J2)
21140 NEXT J2
21150 REM--------------------NO. OF FRAGMENTS IN POLAR ZONES-----------
21160 GOSUB 21710
21170 GOSUB 22270
21180 GOSUB 22480
21190 RETURN
21195 REM----------END OF FRAGMENT PREDICTION SUBROUTINE--------------
21200 REM ------------------WEIGHT DISTRIBUTION INPUT----------------
21210 FOR J=1TO J9
21220 READ M(J)
21230 NEXT J
21240 FOR M5=1TO 2*L1+K1
21250 READ M1(M5)
21260 IF M1(M5)<=50 THEN 21290
21270 U6= 20+(7/15)*(M1(M5)-50)
21280 GO TO 21300
21290 U6=20+0.4366*(M1(M5)-50)
21300 FOR J=1 TO J9
21310 X1=M(J)/U6
21320 X2=SQR(X1)
21330 X3=EXP(-X2)
21340 N(M5,J)=7.70925*X3/U6
21350 W2(M5,J)=X3*(0.5*X1+X2+1)
21360 NEXT J
21370 NEXT M5
21380 RETURN
21390 REM-------------ANGLE A9(M5+1/2)
21400 B1=V(K,L)*U5
21410 B2=U(K,L)*V5
21420 B3=U(K,L)*U5
21430 B4=V(K,L)*V5
21440 B5=SQR(B1*B1+B2*B2+B3*B3+B4*B4)-B3+B4
21450 IF ABS(B5)<E7 THEN 21600
21460 A4=(B1+B2)/B5
21470 A5=A4*(R0-R5)+Z5-Z0
21480 A6=A4*A4
21490 A7=A5*A5
21500 R6=SQR(A6*A7-(A6+1)*(A7-D1*D1))
21510 R6=R0+(R6-A4*A5)/(A6+1)
21520 Z6=Z5+A4*(R6-R5)
21522 IF M5<L1+1 THEN 21525
21523 IF M5>K1+L1 THEN 21525
21524 GO TO 21530
21525 IF (Z6-Z0)*(Z5-Z0)<0 THEN 21600
21530 IF ABS(Z6-Z0)<E7 THEN 21580
21540 A8=ATN((R6-R0)/(Z6-Z0))*180/P9
```

TABLE A-I (CONT.)

```
21550 IF Z6-Z0<0 THEN 21650
21560 A9(M5)=180-A8
21570 GO TO 21660
21580 A9(M5)=90
21590 GO TO 21660
21600 IF Z5-Z0<0 THEN 21630
21610 A9(M5)=180
21620 GO TO 21660
21630 A9(M5)=0
21640 GO TO 21660
21650 A9(M5)=-A8
21660 REM
21670 W6(M5)=W(K,L)
21680 PRINT M5,K,L,W6(M5),A9(M5)
21690 RETURN
21700 REM
21710 REM-------------------NO. OF FRAGMENTS IN POLAR ZONES------------
21720 PRINT"M5","MBAR"
21730 FOR M5=1 TO 2*L1+K1
21740 PRINT M5,M1(M5)
21750 NEXT M5
21760 PRINT
21770 FOR J6=1 TO 36
21780 FOR J=1TO J9
21790 IF J=J9 THEN 21850
21800 N3(J6,J)=N7(J6,J)-N7(J6,J+1)
21810 X1=W5(J6,J)-W5(J6,J+1)
21820 IF J6<>36 THEN 21840
21830 N3(J6,J)=N3(J6,J)+N7(37,J)-N7(37,J+1)
21840 GO TO 21890
21850 N3(J6,J)=N7(J6,J)
21860 X1=W5(J6,J)
21870 IF J6<>36 THEN 21890
21880 N3(J6,J)=N3(J6,J)+N7(37,J)
21890 M6(J6,J)=X1*P6/N3(J6,J)*15.4324
21900 N8(J6)=N8(J6)+N3(J6,J)
21910 NEXT J
21920 Y9(J6)=N8(J6)/Y8(J6)
21930 NEXT J6
21940 PRINT
21950 FOR J6=1TO 36
21960 FOR J=1TO J9
21970 Q6(J6,J)=N3(J6,J)/N8(J6)
21980 NEXT J
21990 NEXT J6
22000 PRINT" NO. OF FRAGMENTS IN POLAR ZONES"
22010 PRINT"WT. RANGES IN GRAINS"
22020 PRINT
22030 J=1
22040 GOSUB 22140
22050 PRINT
22060 J=5
22070 GOSUB 22140
22080 PRINT
22090 PRINT" POLAR ZONE",M(J9-1)"-"M(J9),"GT. THAN"M(J9)
22100 FOR J6=1 TO 36
```

TABLE A-1 (CONT.)

```
22110 PRINT J6,N3(J6,J9-1),N3(J6,J9)
22120 NEXT J6
22130 RETURN
22140 REM ---------------PRINT NO. OF FRAGS IN POLAR ZONES--------------
22150 X(1)=M(J+1)
22160 X(2)=M(J+2)
22170 X(3)=M(J+3)
22180 X(4)=M(J+4)
22190 PRINT≡FZ≡,M(J)≡-≡X(1),X(1)≡-≡X(2),X(2)≡-≡X(3),X(3)≡-≡X(4)
22200 FOR J6=1 TO 36
22210 FOR M2=J TO J+3
22220 N3(J6,M2)=N7(J6,M2)-N7(J6,M2+1)
22230 NEXT M2
22240 PRINT J6,N3(J6,J),N3(J6,J+1),N3(J6,J+2),N3(J6,J+3)
22250 NEXT J6
22260 RETURN
22270 REM-------------------PRINT LETHAL AREA INPUT-----------------
22280 PRINT
22290 PRINT≡ LETHAL AREA INPUT≡
22300 PRINT≡M=AV. WT IN GRAINS≡
22310 PRINT≡ Q=FRACTION OF NO. IN ZONE > 1 GRAIN≡
22320 FOR J6=1 TO 36 STEP 2
22330 PRINT (J6-1)*5≡-≡J6*5,≡-≡,≡-≡, J6*5≡-≡(J6+1)*5
22340 PRINT ≡M≡,≡Q≡,≡-≡,≡M≡,≡Q≡
22350 FOR J=1 TO J9
22360 PRINT M6(J6,J),Q6(J6,J),≡-≡,M6(J6+1,J),Q6(J6+1,J)
22370 NEXT J
22380 PRINT
22390 NEXT J6
22400 PRINT
22410 PRINT
22420 PRINT ≡AV WT=AV WT IN GRAINS OF FRAGMENTS>1 GRAIN≡
22430 PRINT ≡ POLAR ZONE≡,≡INIT. VEL.(FPS)≡,≡FRAG/STER≡,≡AV WT(GRAINS≡
22440 FOR J6=1 TO 36
22450 PRINT(J6-1)*5≡-≡ J6*5,Y(J6),Y9(J6),W8(J6)/N8(J6)*Q9
22460 NEXT J6
22470 RETURN
22480 REM -----------MAKE JMEM DECK FOR LETHAL AREA INPUT --------------
22490 Y1(0)=ABS(U(1,0))*32808
22500 Y1(36)=ABS(U(K1,0))*32808
22510 FOR J6=1 TO 35
22520 Y1(J6)=(Y(J6)+Y(J6+1))/2
22530 NEXT J6
22540 RESTORE FILE(TAPE1)
22550 FOR J6= 1 TO 36
22560 PRINT FILE(TAPE1)(J6-1)*5,J6*5,(J6-.5)*5,Y1(J6-1),Y1(J6),Y(J6),J9
22570 FOR J=1TOJ9
22580 PRINT FILE(TAPE1)M6(J6,J);
22590 NEXT J
22600 PRINT FILE(TAPE1)
22610 FOR J=1 TO J9
22620 PRINT FILE(TAPE1)N3(J6,J);
22630 NEXT J
22640 PRINT FILE(TAPE1)
22650 NEXT J6
22660 RETURN
```

TABLE A-I (CONT.)

```
22670 DATA 3,3.05,2.35,3.85,3.2,4.65
22680 DATA 3.85,5.07,4.2,5.3,4.23,5.37
22690 DATA 4.07,5.26,3.86,5.27,3.65,5.27,3.45,5.27
22700 DATA 3.27,5.4,2.97,5.17,2.97,4.57
22710 DATA 1,2,5,10,15,25,50,100,150,250
22720 DATA 200,200,200,105,105,100,75,55,40,30
22730 DATA 35,35,45,50,70,95,110,130,145,160
22740 DATA 190,65,65,20,35,45,45
30000 END
```

Table AII

Notes on Fragment Prediction Code List

Statement Number	Notes
	INPUT AND INITIALIZATION
1000	Identification
1010-1050	Fixed constants, π, 2π, $2\pi \cdot 15.4185$, $5\pi/180$, $2\pi/454$.
1060-1100	Calculate and store the number of steradians in each 5° polar zone, for use in the fragment prediction scheme (see Fig.9). The area of the curved surface of a spherical segment of height h, of unit radius, is $2\pi h$, or $2\pi(1-\cos\alpha)$, where α is the polar angle. The surface area, or number of steradians, between the polar angles α_1 and α_2 is then $2\pi(\cos\alpha_2-\cos\alpha_1)$.
1110-1300	These are constants for the computation, defined in Table AI.
1310	Equation of state constants are gotten from the equation of state subroutine (8450-8900).
1320-1370	Constants used in the computation are printed out.
1380-1500	Dimension statements for subscripted variables. The dimensions and descriptions are listed in Table AIII.
	GRID POINT INPUT AND INITIALIZATION
1510-1780	Dimensions in cm, taken from drawings of the weapon casing and fuze, are inserted here. At the same time, the values of the interior grid points are obtained, either by uniform spacing or by reading in special

Table AII - continued

Statement Number	Notes

values. The example in the program list (Table AIV) is for the 105 mm projectile, which has a curved base (see Fig.3). Special grid point entries were made in order to get more uniform cell sizes in the base region, and to meet the requirement that each cell have four corners. These special entries are not needed if the base walls are essentially perpendicular to the axis, as in the 155 mm and 5"/54 cal. projectiles. Input and initialization for the example, the 105 mm projectile, were done as follows:

Dimensions, in cm, were obtained from a drawing of the weapon casing. The fuze was replaced with a steel plug in the nose. Also plane detonation of the HE, starting at the nose was assumed.

1510-1550: Enter metal boundary points on the axis (see Fig.1).

1560-1590: Initialize $Z_{K,0}$ values by putting uniform spacing between $Z_{1,0}$ and $Z_{K1,0}$.

1600-1610: Input special coordinates for the axis points.

1630: Read in $R_{K,L1}, R_{K,L1+1}$ $(0 \leq L < L1+1)$ in cm, taken from the drawing, assuming $Z_{K,L1+1} = Z_{K,L1} = Z_{K,0}$. This can be done, one K line at a time, in 9910. To reduce the number of data entries one can read in every other R value between K=1 and K=K1, and have the program produce the intermediate points. This is done in 9960. In the example (Table AI) 9960 was used and the data appear in 22670-22700.

1650: Special $R_{K,L1}, R_{K,L1+1}$ values, replacing those already inserted, are put in here, to make the cells more uniform in the base region. This was done in 10070.

1660-1740: Grid point coordinates are calculated, using uniform spacing.

Table AII - continued

Statement Number	Notes
	1750-1780: Special $Z_{K1,L}$ values are inserted here to replace those just calculated for the line $K=K1$
	FRAGMENT WEIGHT DISTRIBUTION INPUT
1790	Fragment weight distribution input. In the example (Table AI), the Mott distribution is used and the weight distribution is calculated, from Eqs. (82) and (83), in 21200.
	CASING DIMENSION PRINTOUT
1820-1870	Print out coordinates $Z_{K,L}, R_{K,L}$ for K=0 to K1+1, L=0 to L1+1. Notice that this includes the outer boundary of the metal, which will be used only to calculate the masses associated with the mass points. To bypass this print out insert 1805 GO TO 1875.
	INITIALIZE $Z3_K, R3_K$
1890	Initial values of the slide points $Z3_K, R3_K$ are taken as $Z_{K,L1}, R_{K,L1}$, respectively. This is done in 11040-11080.
	SET Z FOR LIGHTING
1910	Set $Z = Z^{\circ}_{K4+1,0}$. This is the value of $Z_{K,0}$ where the HE column starts. In the burn fraction calculation for the plane detonation case, the distance that the detonation front has traveled is measured from this line.
	INITIAL CELL DENSITIES
1930	The initial densities, of the fuze material or the undetonated HE, are stored for the individual cells as $R2_{K,L}$. This refers to the cell with the lower left corner at (K, L).
	COORDINATES OF ZONE CENTERS: ZONE MASSES
1970-2050	Calculate coordinates of zone centers by averaging the coordinates of the corners. Calculate the scaled masses, $W1_{K,L}$ associated with the cells. This is done

Table AII - continued

Statement Number	Notes
	with 7300-7380, which locates the cell corners, (Fig.A1), and 7390-7720, the subroutine which cuts the cell into two triangles and calculates their areas, volumes, and scaled masses. In 2030, W5 is the sum of the scaled masses of the two triangles, calculated in 7390-7720.
	INTERIOR GRID POINT MASSES
2070-2200	Get scaled masses associated with the interior grid points. The centers of the adjacent cells are located in 2070-2160, and the triangle subroutine 7390-7720 is used.
	INTERIOR AXIS POINT MASSES
2220-2300	Scaled masses $w_{K,L}$ associated with the axis grid points are found by calculating the scaled masses of the two quarter cells at the points. Subroutines starting in 8090 and 8180 (see Fig.A1) are used to locate the corners of the quarter cells.
	MASS CORRECTION AT THE FUZE-HE BOUNDARY
2320-2360	In the calculation of the scaled masses associated with the interior grid points (2070-2200), the densities of the cells with (K,L) at the lower left were used. For grid points on the line K=K4+1 ($K4>0, 0\leq L\leq I1-1$), this is now corrected to take into account different initial densities on both sides of the line. Here R2 is the fuze material density and R3 is the HE density. It is assumed that the cells on both sides of the line K=K4+1 are of the same length in the z direction. Otherwise, these masses should be gotten by calculating the masses of the quarter cells on both sides of the line.
2380-2870	Scaled gas masses $w3_{K,L}$ associated with the metal mass points are calculated (see Fig.5). If the boundary point is not a corner point, these are the sums of the

Table AII - continued

Statement Number	Notes
	scaled masses of the two adjacent quarter cells. If the point is a corner point, (1,0), (1,L1), (K1,L1), or (K1,0), $W3_{K,L}$ is the scaled mass associated with the adjoining quarter cell. The subroutines in 7290-8440 are used.
2880-3600	The scaled masses associated with the metal mass points are calculated here, with the subroutines in 7290-8440. The metal is split up as in Fig.5. In the example used here, the 105 mm. projectile, special coding for the base end was done, so that the lines dividing the masses would be perpendicular to the lines joining them, as shown in Fig.3. This special coding, done in 9110-9730, is called with 3560-GOSUB 9110. An alternate arrangement, useful if the base is perpendicular to the axis, is shown in Fig.A3. This is done with the statement 3560-GOSUB 8910.
	PRINTOUT OF GRID POINT AND ZONE CENTER COORDINATES, AND SCALED MASSES
3610-3750	Printed out here are the coordinates of the zone centers, $Z1_{K,L}, R1_{K,L}$, the scaled zone masses $W1_{K,L}$, the grid point coordinates $Z_{K,L}, R_{K,L}$ and the scaled masses associated with the grid points and metal mass points $W_{K,L}$. This printout can be bypassed by inserting the statement 3625 - GO TO 3760.
	C/M RATIO AND SCALE FACTOR
3770-3850	The C/M ratio and χ, defined in Eq. (80) are calculated and printed out here, for the metal at the cross sections where K=1 to K1. These are used to get from Fig.10 or a similar relationship, the values of $\bar{M}$ to assign to the mass points on the side wall of the projectile. It

Table AII - continued

Statement Number	Notes
	is usually convenient to stop the program at this point, with the statement 3855 - GO TO 30000. After the values of $\bar{M}$ for the various mass points, determined from the calculated χ values, are put in as data for the fragment prediction scheme, which starts at 20000, the statement 3855 is removed and the entire program is run from the beginning.
	INITIALIZE N, T, AND FLOW VARIABLES
3870	Set the cycle number N=0.
3880	Set the initial time equal to that for the detonation front to traverse half of the first HE cell.
3900-4000	Initialize $V1_{K,L}$ and $E2_{K,L}$. Usually, to start, $V1_{K,L}=1$, $E2_{K,L}=0$ in the fuze material region, and $E2_{K,L}=E1(=\rho_0 \widetilde{E1})$ for the HE cells.
4020-4070	Initialize the velocity components $U_{K,L}$ and $V_{K,L}$
4080-4140	Initialize the intermediate slide points $Z4_K$, $R4_K$, and the marker points $K9_K$.
4145	Convert dimensions of D1, the arena radius, from ft to cm.
	ENERGY CHECK FOR CYCLE ZERO
4160	The total energy in the system, at cycle zero, before the computation starts, is found and printed out here with the energy check subroutine that is used later at the end of each cycle.

Table AII - continued

Statement Number	Notes
	FLUID DYNAMICS - MAIN ROUTINE
4180	Advance time cycle number.
4190	Exit if time exceeds T4 microseconds.
4200	Exit if cycle number exceeds N6
4210	Advance time (see Eq. (17)).
4220-4330	K3 for limited computation is calculated (Eq. (18)). This is done to save computing time, by not calculating over portions of the grid where nothing is happening. For the cycle, K3 is the maximum K for which new values of the variables located at the cell centers are calculated. If K3=K1-1, the motions of the end points (K1,L) are also calculated.
4340	The new cycle number N and the new time T^{n} are printed.
	NEW POSITIONS
4360-4480	Equations (19) are used here.
4500	New slide point positions $Z3_{k}, R3_{k}$ and related variables are calculated in 10200-10650
	NEW VALUES OF VARIABLES LOCATED AT THE CELL CENTERS
4530	This is the start of a double loop which ends at 4960. New values of $V1^{n}_{k,l}$, $Q1^{n-1/2}_{k,l}$, $P2^{n}_{k,l}$, $E2^{n}_{k,l}$, $C2^{n}_{k,l}$ $T2^{n}_{k,l}$ are calculated in this loop.

Table AII - continued

Statement Number	Notes
4550	Saves old $P1_{K,L}(=P2_{K,L}-Q1_{K,L})$ temporarily.
4560	Saves old $V1_{K,L}$ temporarily.
4570-4620	New cell areas and relative specific volumes, $A1^{N}_{K,L}$ and $V1^{N}_{K,L}$, are calculated with the same triangle subroutine used for the initialization (7300). If $L < L1-1$, subroutine 7300 is used to get the cell corners. If L=L1-1, 10660-10750 is used. This takes into account the fact that the upper corners of the cells, for this case, are $(Z3_K, R3_K)$ and $(Z3_{K+1}, R3_{K+1})$.
4630	$V6 = V1^{N}_{K,L} - V1^{N-1}_{K,L}$
4640	$V7 = (\dot{V1})^{N-1/2} = (dV1/dT)^{N-1/2}$
4650	$V8 = V1^{N-1/2}_{K,L}$
4660	$V9 = (\dot{V1}/V)^{N-1/2}_{K,L}$
4670-4700	$Q1^{N-1/2}_{K,L}$ is calculated with Eqs. (29) and (30).
	BURN FRACTION
4730	If all F_K now equal one, no burn fractions need be calculated.
4740	This is the plane detonation case. For each K the burn fraction is the same for all L. This is calculated when L=0, in 11740-11910.
4750	$P2^{N}_{K,L}$, $E2^{N}_{K,L}$ and $C2^{N}_{K,L}$ are calculated in the equation of state subroutine (8450-8900).

Table AII - continued

Statement Number	Notes
4770-4940	The time step for the (K,L) cell, $T3^{N}_{K,L}$ is calculated with Eqs. (33)-(35). Notice that $(Z3_{K}, R3_{K})$ and $(Z3_{K+1}, R3_{K+1})$ are the upper corners of the cells when L=L1-1.
4950	Save old time step temporarily.
4990-5060	T5 is the minimum of the cell time steps $T3^{N}_{K,L}$
5070-5110	The new time steps $T1^{N+1}_{K,L}$ and $T2^{N+1/2}_{K,L}$ are found with Eqs. (36) and (37).
	$Z4_{K}, R4_{K}$ FOR SLIDING
5130	Intermediate slide point positions $Z4_{K}, R4_{K}$ are found in 11090-11390, while the old velocities $U^{N-1/2}_{K,L1-1}, V^{N-1/2}_{K,L1-1}$ are still available.
	VELOCITY OF INTERIOR GRID POINTS
5150	New interior grid point velocities $U^{N+1/2}_{K,L}, V^{N+1/2}_{K,L}$ are calculated in 10830-11020, with the scheme in Eqs. (50)-(54).
	VELOCITIES OF INTERIOR AXIS POINTS
5380-5530	The new velocity components of the interior axis points are gotten with Eqs. (56)-(58). Subroutines used in the initialization are used here to calculate the volumes of the two quarter cells associated with the axis grid points. Extrapolation of the pressure to the axis, in the radial direction, is not done because $dv/dT=0$ on the axis. This implies, from (9), that $\partial P2/\partial R=0$ on the axis. Hence, the pressure can be assumed uniform between $R=0$ and $R_{K,1}/2$.
	VELOCITIES OF METAL MASS POINTS
5560-5580	$U_{1,0}$ is the axial velocity component of the axis mass

Table AII - continued

Statement Number — Notes

point on the left boundary. The pressure associated with the point is taken, by extrapolation, to be $-(3PZ^n_{1,0} - PZ^n_{2,0})/2$. The difference form of Eq.(10) is used, with $\tilde{A}_Z = \pi(R_{1,1}/2)^2$.

5600-5810

Velocity components of the mass points on the line K=1 (L≠0) are found by using Eqs. (64) and (65), with appropriate subscripts. For example, for K=1, L=L1

$\tilde{A}_R = \pi(R_2^2 - R_1^2)$, where $R_2 = (R_{1,L1} + R_{2,L1})/2$, $R1 = (R_{1,L1} + R_{1,L1-1})/2$,
and

$$\tilde{A}_Z = 2\pi[(Z_{1,L1} - Z_{1,L1-1})/2][(3R_{1,L1} + R_{1,L1-1})/4] + 2\pi[(Z_{2,L1} - Z_{1,L1})/2][(3R_{1,L1} + R_{2,L1})/4]$$

For the corner mass point (1,L1) the corner cell pressure is used, i.e., in Eq. (10) $PS = -PZ_{1,L1-1}$ is used in calculating the axial component, and $PZ_{1,L1-1}$ is used in calculating the radial component. The opposite signs are needed so that the accelerations will have the correct signs.

5830-5840

Assign pressures in the cells (1,L1-1) and (K3,L1-1) to the slide points $(Z3_1, R3_1)$ and $(Z3_{K3+1}, R3_{K3+1})$, respectively.

5870-5930

Get pressures $P3_K$ at the slide points $Z3_K, R3_K$, $(1 \le K \le K3)$ by extrapolation from the interior, with Eq. (59).

5940

Start of loop for velocity components of mass points $(K, L1)$ for $2 \le K \le K3$.

5950-6040

Finds closest slide points on both sides of the mass point, with Eq. (61). If there is no sign change,

Table AII - continued

Statement Number	Notes
	diagnostics are printed out in 9750-9810 and the program stops.
6050-6070	The pressure at the mass point is found by interpolating between adjacent slide points, using Eqs. (62) and (63).
6080-6190	Calculate mass point velocity components, for $2 \leq K \leq K3$, with Eqs. (64) and (65).
6200	End of loop which starts at 5940.
6210-6220	If $K3 < K1-1$ velocity calculations for the mass points on K=K1 are bypassed.
6240-6520	Velocity component calculations for the mass points on the right boundary,K=K1. The formulas, with appropriate subscripts, are the same as those used for the mass points on the left boundary,K=1.
	FLUID DYNAMICS - PRINT ROUTINE
6560	Values of the flow variables will be printed at the end of the first cycle, before the second cycle is calculated, unless this instruction is deleted.
6570	The fluid dynamics print routine and the fragment prediction routine are entered at intervals of T7 usec (actually, at the first cycles past these times). This is done N5 times. The counter N7 is advanced by one in 7100 each time the fragment prediction scheme is used.
6580	Print routine and fragment prediction bypass.

Table AII - continued

Statement Number	Notes
6590	If the cycle number N is less than N4 the fragment prediction routine is bypassed. Usually the fragment prediction scheme is not used until all the mass points have started to move.
6600	The fragment prediction is done here, starting in 20020.
6610	Prints N and T^N, $T1^{N+1/2}$, $T2^N$ in μsec. Notice that N and T are for the cycle just completed. The time step $T1^{N+1/2}$ is for use in the next cycle, and $T2^N$ was used to calculate the new velocity components.
6650	The flow variable printout can be bypassed on every cycle, if one is just interested in the fragment prediction results, by inserting the statement 6650 GO TO 7080.
6660	Start of flow variable printout loop. BASIC programming now allows for a maximum of five numbers per line.
6670	Prints K, the burn fraction F_K (this is the plane detonation case), and the metal velocity, i.e., $(U^2+V^2)^{1/2}$, for the mass point at (K,L1), in ft/sec.
6680-6710	Prints L, Z and R coordinates, and velocity components. Units are cm and cm/μsec.
6730-6760	Prints L, $P2_{K,L}$ (mbar), $Q1_{K,L}$ (mbar), $V1_{K,L}$[(cc/gram)$\cdot\rho_0$] and $E2^N_{K,L}$ [(mbar-cc/gram)$\cdot\rho_0$]
6770-6800	Prints K, L, $T3_{K,L}$ (μsec), and $C2^N_{K,L}$ [(cm/μsec)^2].
6810	End of loop.

Table AII - continued

Stat[illegible]	Notes
[illegible]	If $K3 < K1-1$ the printout for the line K=K1 is bypassed.
6830-6880	Prints L, Z and R coordinates, and velocity components for the right end mass points.
6920-6950	Prints positions of slide points $Z3_K, R3_K$ and associated pressures $P3_K$. Recall that the adjoining cell values of $P2_{K,L}$ are used for the corner points (5830-5840) and the other values are gotten by extrapolating $P2_{K,L}$ values in (5870-5930).
6970-7030	Prints velocities $(U^2+V^2)^{1/2}$ of end mass points in ft/sec. The velocities are calculated in 11920-11960.
7040-7070	Prints out values of variables $K9_K, Z4_K, R4_K, S8_K$, used in the slide routine. Note that $Z4_K, R4_K$ are calculated for use during the next cycle. The variable $K9_K$ denotes the K value of first mass point to the left of the Kth slide point. If $(Z3_K, R3_K)$ and $(Z_{K,L1}, R_{K,L1})$ coincide, $K9_K = K-1$ The variable $K9_K$ is used in 11090-11390 to locate the line segment along which the point $(Z3_K, R3_K)$ moves to $(Z4_K, R4_K)$. In another version of the program which allows for free gas expansion out the ends of a tube, it is used to tell if a slide point is inside or outside the tube. If it is outside $K9_K = 0$ or K1.
7090	Does energy check if N=1 and returns to the beginning of the main routine.
7100	Advances N7 (see statement 6570).

Table AII - continued

Statement Number	Notes
7110	Exit if $T \geq T7 \cdot N5$.
7130	Does energy check (in .0-11730) every cycle. Provision to stop the program if the total energy varies by more than a prescribed amount can be inserted at this point. For example, put 4095 E9=E 7132 If ABS (E-E9) < 1.1 E9 then 7140 7133 Print "STOP ON ENERGY CHECK" 7135 GO TO 30000
7160	Return to start of main routine.
	SUBROUTINES AND TRANSFERS
	INITIAL DENSITIES OF CELLS
7190-7280	Initialize HE and fuze cell densities $R2_{K,L}$. It is assumed here that the HE column starts at $K=K4+1$. Special initial densities can be assigned to individual cells in 7271-7279.
7290	MASS, VOLUME, AND AREA These routines are used in the initialization and in the calculation of $V1^{N}_{K,L}$ and $U^{N-1/2}_{K,L}$ $(2 \leq K \leq K3)$.
7300-7380	Locates corners of cell with (K,L) at lower left (see Fig.A1).
7390-7720	Calculates area, scaled volume and scaled mass of quadrilateral with corners (G_i, H_i), $i = 1$ to 4, by dividing it into two triangles and using Eqs. (1) and (2). At large expansions the corner cells (1,L1-1) and (K1-1,L1-1) tend to become concave if the masses associated with the corner points are large relative

Table AII - continued

Statement Number	Notes
	to the masses of the adjacent points. The subdivision into triangles is done differently for the left and right sides (see Fig.A2), in order to get the true areas of these corner cells.
7730-7810	Locates corners of half cell with (K,L) at lower left and (K+1,L) at lower right (Fig.A1).
7820-7900	Locates corners of half cell with (K,L) at upper left and (K+1,L) at upper right (Fig.A1).
7910-7990	Locates corners of half cell with (K,L) at lower right and (K,L+1) at upper right (Fig.A1).
8000-8080	Locates corners of half cell with (K,L) at lower left and (K,L+1) at upper left (Fig.A1).
8090-8170	Locates corners of quarter cell with (K,L) at lower left (Fig.A1).
8180-8260	Locates corners of quarter cell with (K,L) at lower right (Fig.A1).
8270-8350	Locates corners of quarter cell with (K,L) at upper right (Fig.A1).
8360-8440	Locates corners of quarter cell with (K,L) at upper left (Fig.A1).
	EQUATION OF STATE SUBROUTINE
8460-8480	If N=0, the equation of state constants are entered and printed out with 8760-8900. Notice that this

Table AII - continued

Statement Number	Notes
	subroutine must be called before the cell and grid point masses are computed, because it contains the value of R3, the solid HE density. (This is done in 1310.)
8490	If $1 \le K \le K4$ then $P2^n_{k,l}, E2^n_{k,l}, C2^n_{k,l}$ are calculated for the inert fuze material between the lines K=1 and K=K4+1. This is done in 10150-10190.
8500	Set N2=0. This is the counter for the iteration which solves for the pressure and energy.
8510-8530	The equation of state used here is Eq. (11), with C4 and C5 from Eq. (13).
8540	Saves the old energy $E2^{n-1}_{k,l}$ temporarily, as E6.
8550-8620	Solution of Eqs. (6)-(8), by iteration. The iteration is done only once. The iteration can be done by the method in the HEMP Code[2], by inserting the statement 8535 GO TO 9830.
8630-8660	Calculates the sound speed squared, $C2^n_{k,l}$ using Eq. (12).
8680-8740	Diagnostics if the calculated value of $C2^n_{k,l}$ is negative. This will cause the program to stop when it attempts to take a negative square root in the time step calculation (4940).
8760-8840	Put detonation product equation of state constants here. The constant $Q3\ (= 1 - V1_{CJ})$ where $V1_{CJ}$ is the relative specific volume at the Chapman Jouguet state is used in the burn fraction calculation (Eq. (25)).

Table AII - continued

Statement Number	Notes
8850-8880	Printout of equation of state constants the first time the routine is called (1310).
	SPECIAL CODING FOR BASE END MASSES
8910-9100	This routine reduces the mass of the mass point at the base corner (K1,L1) and adds the mass removed to the adjoining mass points (K1-1,L1) and (K1,L1-1). The metal then associated with the three mass points is shown in Fig.A3. To use this routine insert 3560 GOSUB 8910.
9100-9730	Special coding for the masses associated with the mass points can be done here. In this particular case, the 105 mm projectile base (Fig.3) is split up so that the separation lines are perpendicular to the lines joining the mass points, and the associated masses are calculated. The routine is called in 3560, with GOSUB 9100.
	MASS POINT PRESSURE - DIAGNOSTIC PRINTOUT
9750-9820	Diagnostic printout if J>K1-1 in the mass point pressure routine, i.e., if the two adjacent slide points are not found. It is called in 6030.
	ALTERNATE PRESSURE ENERGY ITERATION
9830-9900	Alternate method, used in HEMP[2] for the pressure, energy iteration in the equation of state routine (8450-8900). Insert with 8535 GO TO 9830.
	INPUT METAL BOUNDARY POINTS
9910-9950	Input of metal boundary points, one K line at a time. Called with 1630 GOSUB 9910.
9960-10060	Input of metal boundary points, every other K line between K=1 and K=K1. The intermediate points are put in automatically, with 10020-10050. Called with 1630 GOSUB 9960.

Table AII - continued

Statement Number	Notes
10070-10130	Input special values for metal boundary grid points. This is needed, for example, when the base is curved, as in the 105 mm projectile. Called with 1650 GOSUB 10070.
	EQUATION OF STATE OF FUZE CELLS
10140-10190	Equation of state for cells with $1 \leq K \leq K4$. Calculate $P2^n_{K,L}$, $E2^n_{K,L}$, $C2^n_{K,L}$ here. Called with 8490.
	SLIDE ROUTINE ($Z3_K$, $R3_K$, $K9_K$, $S8_K$)
10200-10650	The new slide points $Z3_K$, $R3_K$ and the related values $K9_K$ and $S8_K$ are found here (see Eqs. (20)-(24)). The values of $S8_1$ and $S8_{K1}$ in 10630 and 10640 are fictitious, inserted for use in the mass point pressure calculation (5960,5970).
10660-10750	Locates cell corners when the upper corners are slide points (L=L1-1). Called in 4580.
11030-11080	Initialize slide points $Z3_K$, $R3_K$ by setting them equal to $Z_{K,L1}$, $R_{K,L1}$, respectively. Called in 1890.
11090-11390	Intermediate slide points $Z4_K$, $R4_K$ (see Fig.6) are calculated with Eqs. (38)-(49). Notice that the pressures in the (K,L1-1) cells are used to move the two quarter cells associated with a slide point. This is done because the assumption that the boundary is being held fixed while the gas slides implies that the normal pressure gradient is zero there. Called in 5130.
	ENERGY CHECK
11410-11730	The gas internal energy, the kinetic energies of the gas and the metal mass points, and the total energy in the system are summed with Eqs. (66)-(68) and printed out. Here

Table AII - continued

Statement Number	Notes
	E3 = internal energy in the gas (mbar-cc),
	E4 = kinetic energy in the gas (mbar-cc),
	E5 = kinetic energy in the metal (mbar-cc),
	E = total energy in the system = E3+E4+E5.
	Called before the first cycle, in 4090 (this is the total energy released by the HE), and at the end of every cycle, in 7130.
	BURN FRACTION (PLANE DETONATION)
11740-11910	The burn fraction F_K is calculated from Eq. (25). Called in 4740.
11920-11960	Velocities of the end mass points, L=0 to L1-1, are calculated from the components $U_{K,L}$ and $V_{K,L}$ and printed out in ft/sec.
11970	EXIT.

(Continued on the following page)

Table AII - continued

FRAGMENT PREDICTION SCHEME

Statement Number	Notes
	TOTAL WEIGHT OF FRAGMENTS IN EACH POLAR ZONE
20040-20090	Sets all W7(J2,M5)=0. The variable W7(J2,M5) is the scaled mass (in grams) of the fragments in polar zone J2, which come from the mass point M5. The J2 nd polar zone lies between polar angles $5(J2-1)\leq\alpha<5J2$. Thus polar zone number 36 lies between $175\leq\alpha<180$, and polar zone number 37 contains only the 180° direction. Where it is convenient the material in polar zone 37 is included in polar zone 36.
20100	The scaled mass of metal associated with each mass point, $W6_{M5}$ and the angles $A9_{M5+1/2}$ (see Eq. (73)) are found in 20100-20500. Part of the computation of the angles is done in subroutine 21390, which is called from 20250, 20350, and 20450.
20170-20260	The angles $A9_{M5+1/2}$ (see Eq. (73)) and the velocities of the mass points $1\leq M5\leq L1$ are calculated here. The point Z5,R5 is the current position of the midpoint of the line segment joining the mass points M5 and M5+1, taken from the fluid dynamics results. The variables U5 and V5 are the current velocity components of the mass point M5+1. The variable $Q3_{M5}$ is the current velocity of the mass point M5. The computation of the angle $A9_{M5+1/2}$ is explained under 21390-21690. Note that $A9_{M5+1/2}$ is the polar angle associated with the midpoint of the line segment joining mass points M5 and M5+1. The metal mass associated with the mass point M5 is assumed to be distributed uniformly between the angles $A9_{M5-1/2}$ and $A9_{M5+1/2}$.

Table AII - continued

Statement Number	Notes
20270-20360	The current velocities $Q3_{M5}$ and the polar angles $A9_{M5+1/2}$ are calculated for the mass points on the line L=L1.
20370-20460	The current velocities $Q3_{M5}$ and the polar angles $A9_{M5+1/2}$ are calculated for the mass points corresponding to K=K1, L=1 to L1-1.
20470	$A9_0$ is set equal to zero. This is used in calculating the spatial distribution of the mass associated with the mass point M5=1.
20480-20490	The scaled mass and velocity associated with the last mass point, M5=K1+2L1 are calculated here.
20500	For the last mass point, $A9_{2L1+K1+1/2}$ is set equal to 180°.
20520-20610	Various quantities used to get fragment weight distributions in the individual polar zones are set equal to zero.
20650-20910	Here, the scaled mass associated with each mass point M5 is distributed uniformly over the polar region between the angles $A9_{M5-1/2}$ and $A9_{M5+3/2}$. If $A9_{M5-1/2}$ is larger than $A9_{M5+1/2}$ the fragments paths cross, but the treatment is the same. In either case C7 is the smaller and C8 is the larger of the two angles defining the polar region over which $W6_{M5}$ the mass from the point M5 is to be distributed. Also J2 and J3 are the numbers of the polar zones containing C7 and C8 respectively. If C7 or C8 is on the boundary between

Table AII - continued

Statement Number	Notes
	zones J2 and J3 it is assigned to J3. If J2 is equal to J3, all of the mass from the point M5 is assigned to this zone, i.e., $W7_{J2,M5}$, the scaled mass of metal from mass point M5 in polar zone J2, is set equal to $W6_{M5}$. If J2 is not equal to J3, the appropriate scaled masses are assigned to zones J2 and J3 in 20770 and 20780. Appropriate scaled masses are assigned to intervening zones in 20790-20810, with J4 from 20750. The numbers $N7_{J6,J}$ of fragments of weight greater than M_J and the scaled masses $W5_{J6,J}$ of fragments in each of the J9 weight ranges in each of the polar zones are accumulated here. Also the weights of fragments (in grains) from each of the mass points in each of the polar zones are printed out.
20920-20970	The total weight of metal is summed here and printed out, in pounds and in grains.
21010-21140	For each polar zone, the total fragment weight in the zone (in grains), the percent of the total fragment weight in the zone and the average velocity of fragments in the zone (in ft/sec) are calculated and printed out. Here, $W8_{J2}$ is the scaled mass of fragments in the polar zone and the average velocity, in cm/µsec, is $W9_{J2}/W8_{J2}$, where $W9_{J2} = \sum_{M6=1}^{2L1+K1} W7_{J2,M6} \cdot Q3_{M6}$. The average velocity in ft/sec is Y_{J2} (see 21120).
21150	At this point the following subroutines can be called (for details see the notes under the subroutine statement numbers). Subroutine 21710 must be called before either 22270 or 22480, since quantities needed in the latter two subroutines are calculated there.

Table AII - continued

Statement Number	Notes
	21710-Calculates and prints out, for each polar zone, the average weight of fragments in each of the J9 weight ranges (in grains) and the number of fragments in each of these weight ranges. 22270-Values of the average fragment velocity, fragments per steradian, and average fragment weight (in grains) are printed out for each polar zone. This form is useful as input for a particular lethal area program (AMSAA). The calculated values can also be put on tape, from which cards, in a prescribed FORTRAN format, can be punched directly. 22480-Stored values are put on tape for use by a FORTRAN routine (Table AVI) which has the computer punch a card deck suitable for input to the JMEM lethal area program.
21190	End of fragment prediction subroutine which starts at 20020 and is called at 6600, in the fluid dynamics program. WEIGHT DISTRIBUTION INPUT
21200-21230	The left endpoints M_J of the J9 fragment weight intervals (in grains) are read in. The data are in 22710.
21240-21380	In this case the Mott distribution (Eq. (81)) is used. For each mass point M5, the quantity $\bar{M}_{MS}$, the average weight in grains of fragments weighing more than one grain, is read in (the data are in 22720-22740). Then the corresponding μ is calculated with Eq. (83) and $N_{MS,J}$ and $W2_{MS,J}$ are calculated with Eqs. (81) and (84), respectively. Notice that M_J and μ are in grains, $N_{MS,J}$ is in fragments per gram, and $W2_{MS,J}$ is dimensionless.

Table AII - continued

Statement Number	Notes
	POLAR ANGLE SUBROUTINE
21390-21690	The polar angle $A9_{MS+1/2}$ (Eq. (73)) is calculated here. The subroutine is called in 20250, 20350, and 20450. To solve Eqs.(72) one needs tan $\beta_{MS+1/2}$. This is found as follows: Note that $$\tan \beta_{MS+1/2} = \tan \{(\beta_{MS}+\beta_{MS+1})/2\}$$ $$= [1-\cos(\beta_{MS}+\beta_{MS+1})]/\sin(\beta_{MS}+\beta_{MS+1})$$ $$= \frac{1-(\cos\beta_{MS}\cos\beta_{MS+1}-\sin\beta_{MS}\sin\beta_{MS+1})}{\sin\beta_{MS}\cos\beta_{MS+1}-\cos\beta_{MS}\sin\beta_{MS+1}},$$ where $\tan\beta_{MS} = V_{K,L}/U_{K,L}$ and $\tan\beta_{MS+1} = V5/U5$, with U5 and V5 (defined in 20170-20460) the velocity components of the mass point M5+1. Then $\tan\beta_{MS+1/2} = 1/A4$, where A4=(B1+B2)/B5, and B1, B2, and B5 are defined in 21400-21440. Equations (72), with the second part now written $A4(R6-R5)-(Z6-Z5)=0$ is solved simultaneously in 21470-21520. Special cases are treated at the end of the subroutine. It was assumed here that the arena center (ZO, RO) coincides with the center of the weapon. Hence, if the radial velocity component is zero, the angle $A9_{MS+1/2}$ is taken to be 0° for $Z5<ZO$ and 180° for $Z5 \geq ZO$. The scaled metal masses $W6_{MS}$ associated with the mass points are assigned in 21670.
	NUMBER AND AVERAGE WEIGHT OF FRAGMENTS IN EACH WEIGHT RANGE IN POLAR ZONES
21720-21750	Assigned values of M for each mass point are printed out. These are read in at 21250 (the data are in 22720-22740).
21770-21930	The quantities $N3_{J6,J}$, $M6_{J6,J}$, $N8_{J6}$, $Y9_{J6}$ are calculated

Table AII - continued

Statement Number	Notes
	here. Recall that $N7_{J6,J}$ is the cumulative number of fragments of weight greater than M_J in the J6th polar zone. The actual number of fragments in the Jth weight range in the polar zone, $N3_{J6,J}$, is found by difference. Similarly, X1, the scaled weight of fragments in the weight range in the polar zone, is gotten from the $W5_{J6,J}$. The average weight of fragments in the Jth weight range, in the J6th polar zone, $M6_{J6,J}$ is then the weight divided by the number (see 21890). In 21900, $N8_{J6}$, the total number of fragments in the J6th polar zone is accumulated. The number of fragments per steradian in the polar zone, $Y9_{J6}$, is calculated in 21920.
21950-21990	The fraction of the number of fragments in the J6th polar zone, in the Jth weight group, $Q6_{J6,J}$, is calculated here, for all J and J6.
22000-22260	The array $N3_{J6,J}$ which consists of the calculated number of fragments in each weight group for each polar zone, is printed out.
	AMSAA LETHAL AREA PROGRAM INPUT
22270-22470	Quantities needed for the AMSAA lethal area program are printed out here. These are $M6_{J6,J}$ (see 21890), $Q6_{J6,J}$ (see 21970), and for each polar zone the average fragment velocity (there is no correction for air drag), the fragments per steradian $Y9_{J6}$ (see 21920), and the average fragment weight (in grains).
	JMEM LETHAL AREA PROGRAM INPUT
22480-22660	Quantities needed for the JMEM lethal area program are stored on tape for use by a FORTRAN program (Table AVI) which prepares a card deck in the JMEM format. The

Table AII - continued

Statement Number	Notes
	quantity Y_{J6} (see 21120) is the average fragment velocity in the polar zone (ft/sec). $Y1_{J6}$ is the average fragment velocity at the intersection of the polar zones J6 and J6+1. Also, $M6_{J6,J}$ and $N3_{J6,J}$ (see 21770-21930) are used here.
	DATA
22670-22700	Casing dimensions (called in 1630).
22710	Beginnings of fragment weight range intervals (called in 21220).
22720-22740	Average weight of fragments weighing more than one grain, $\bar{M}$, for each mass point (called in 21250).

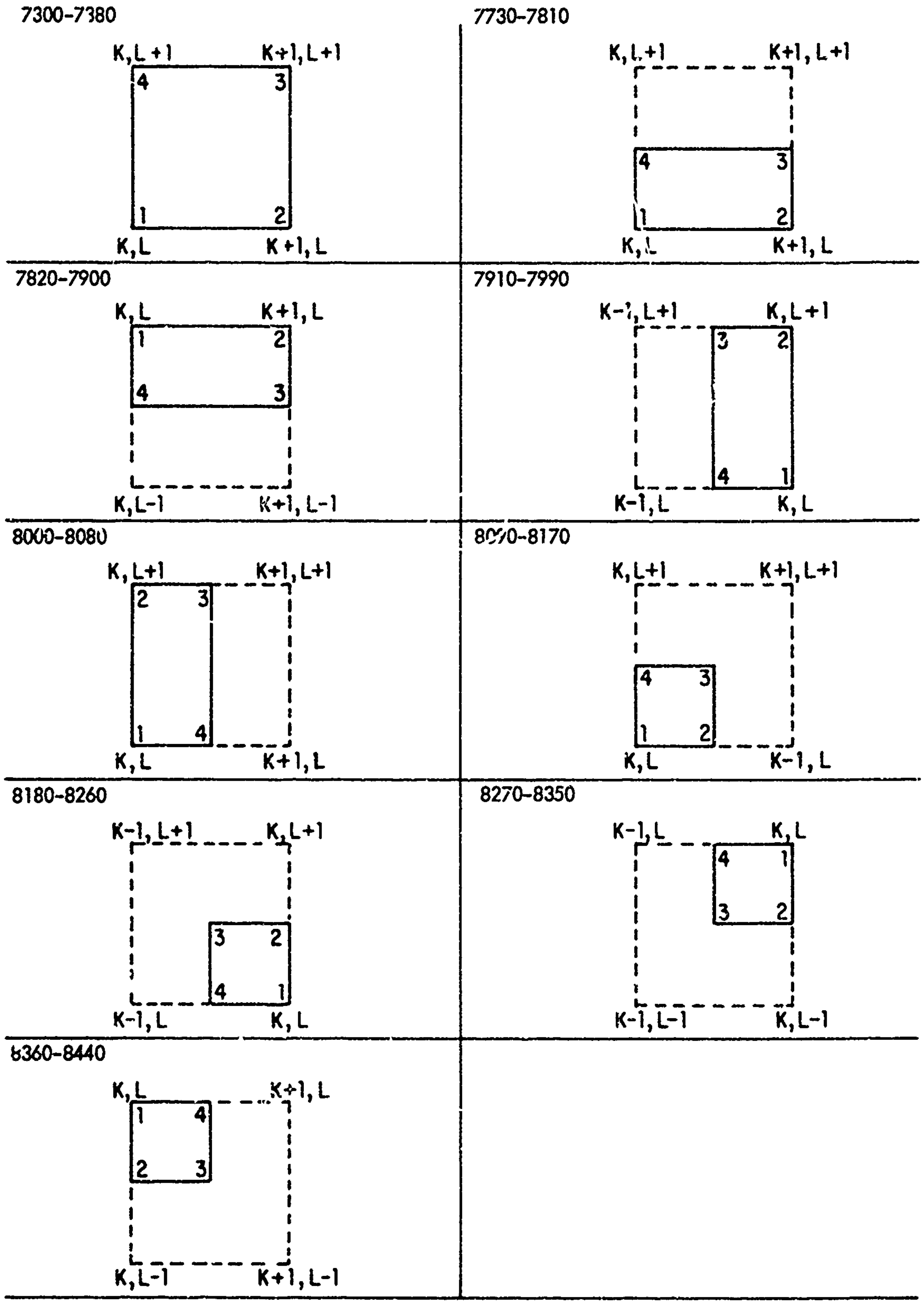

FIG. A1 QUADRILATERALS FOR WHICH THE CORNERS ARE DESIGNATED BY SUBROUTINES

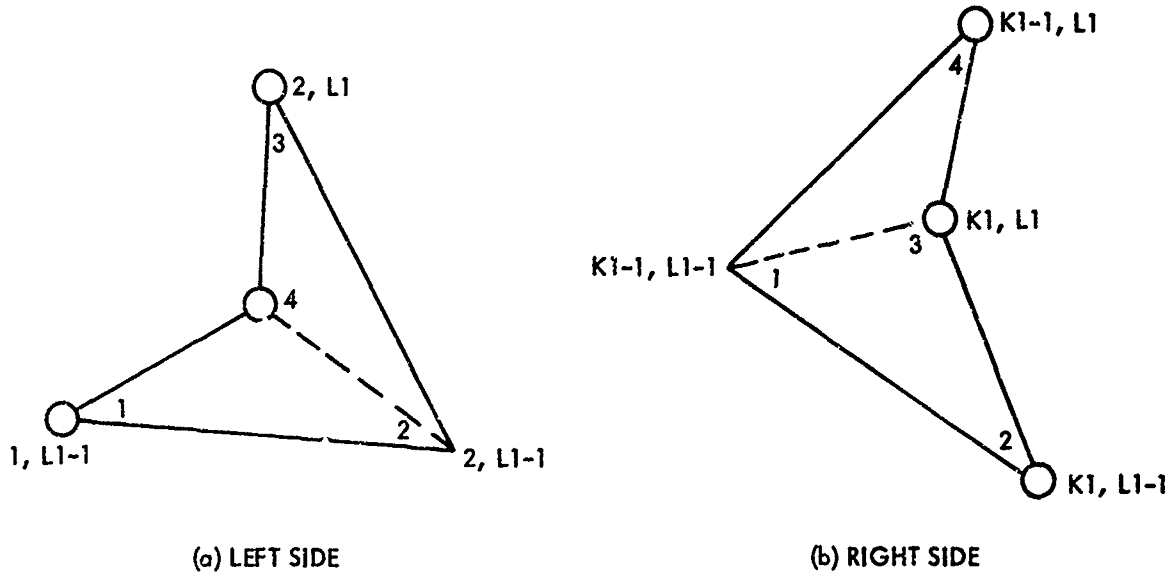

FIG. A2 SUBDIVISION OF CORNER CELLS INTO TRIANGLES FOR AREA COMPUTATION (SHOWN AFTER DISTORTION AT LONG TIMES)

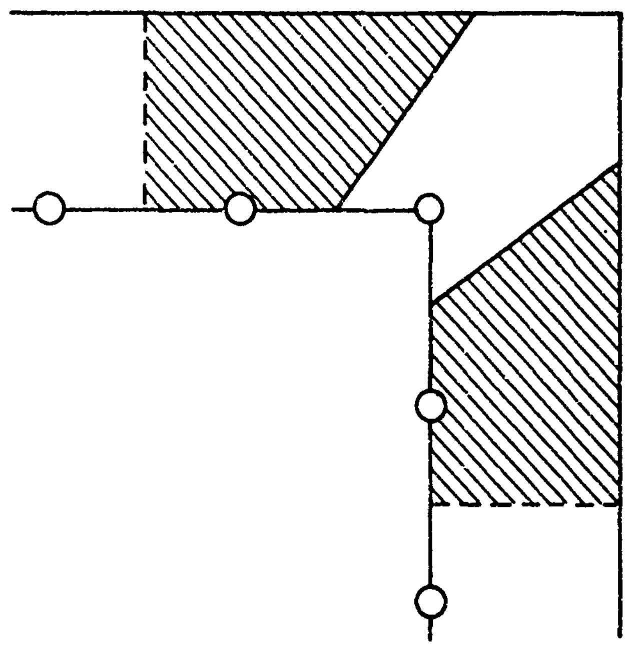

FIG. A3 METAL ASSOCIATED WITH BASE CORNER MASS POINTS, AFTER APPLYING CORNER MASS CHANGE SUBROUTINE 8910-9100

Table AIII

List of Variables - Fragment Prediction Code

Variable and Dimensions	Finite Difference Notation*	Description
R(K1+2,L1+2)	$R^{N}_{K,L}$	Radial coordinate of grid point or metal mass point (cm).
Z(K1+2,L1+2)	$Z^{N}_{K,L}$	Axial coordinate of grid point or metal mass point (cm).
R1(K1-1,L1)	$R1^{N}_{K,L}$	Radial coordinate of cell center (cm).
Z1(K1-1,L1)	$Z1^{N}_{K,L}$	Axial coordinate of cell center (cm).
W(K1,L1+1)	$W_{K,L}$	Scaled mass (mass/2π) associated with interior grid point or metal mass point (grams).
W1(K1-1,L1)	$W1_{K,L}$	Scaled mass (mass/2π) associated with computation cell (grams).
W3(K1,L1+1)	$W3_{K,L}$	Scaled mass (mass/2π) of gas associated with boundary grid point (grams).
U(K1,L1+1)	$U^{N+1/2}_{K,L}$	Axial velocity component of interior grid point or metal mass point (cm/μsec).
V(K1,L1+1)	$V^{N+1/2}_{K,L}$	Radial velocity component of interior grid point or metal mass point (cm/μsec).
V1(K1-1,L1)	$V1^{N}_{K,L}$	Relative specific volume (cc/cc).
V5(K1-1,L1)	$V5^{N-1}_{K,L}$	Old relative specific volume (cc/cc).
Q1(K1-1,L1)	$Q1^{N-1/2}_{K,L}$	Artificial viscosity (mbar).
T3(K1-1,L1)	$T3^{N}_{K,L}$	Cell time step (μsec).
C2(K1-1,L1)	$C2^{N}_{K,L}$	Sound speed squared $(cm/\mu sec)^2$.

* At end of computation cycle.

Table AIII - continued

Variable and Dimensions	Finite Difference Notation*	Description
P2(K1-1,L1)	$P2^N_{K,L}$	Pressure + artificial viscosity(P1+Q1) (mbar).
E2(K1-1,L1)	$E2^N_{K,L}$	Specific internal energy per original cc (mbar-cc/cc).
A1(K1-1,L1)	$A1^N_{K,L}$	Cell area (cm^2).
R2(K1-1,L1)	$R2_{K,L}$	Initial density in cell (grams/cc).
F(K1-1)	F^N_K	Burn fraction -plane detonation front perpendicular to axis.
R3(K1)	$R3^N_K$	Radial coordinate of slide point (cm).
Z3(K1)	$Z3^N_K$	Axial coordinate of slide point (cm).
P3(K1)	$P3^N_K$	Pressure + artificial viscosity at slide point (mbar).
R4(K1)	$R4^{N+1}_K$	Intermediate radial coordinate of slide point (cm).
Z4(K1)	$Z4^{N+1}_K$	Intermediate axial coordinate of slide point (cm).
K9(K1+1)	$K9^N_K$	K coordinate of first mass point to the left of the Kth slide point.
S8(K1)	$S8^N_K$	Negative reciprocal of slope of K line to slide point.
U7(K1)	$U7^{N+1/2}_K$	Axial component of velocity of slide point (cm/μsec).
V7(K1)	$V7^{N+1/2}_K$	Radial component of velocity of slide point (cm/μsec).
N	N	Cycle number.

Table AIII - continued

Variable and Dimensions	Finite Difference Notation	Description
T	T^{N}	Time. (μsec)
T1	$T1^{N+1/2}$	Time step. (μsec)
T2	$T2^{N}$	Time step. (μsec)
Z	$\dot{Z}_{K+1,0}$	Axial coordinate of initial position of detonation front for plane detonation.
P	P	Temporary storage for $P2^{N-1}_{K,L} - Q1^{N-3/2}_{K,L}$.
N3(37,J9)	$N3_{J6,J}$	Number of fragments in the Jth weight range in the J6th polar zone (0°≤α<5° for J6=1, ... ,175°≤α<180° for J6=36, =180° for J6=37).
N7(37,J9)	$N7_{J6,J}$	Cumulative number of fragments of weight greater than M_J grains in the J6th polar zone.
N(2L1+K1,J9)	$N_{M5,J}$	Cumulative number of fragments per gram of weight greater than M_J from the metal mass point M5.
W7(37,2L1+K1)	$W7_{J6,M5}$	Scaled mass (mass/2π), in grams, of fragments from the metal mass point M5, in the polar zone J6.
W2(2L1+K1,J9)	$W2_{M5,J}$	Fraction of mass of fragments from mass point M5, of weight greater than M_J.
W5(37,J9)	$W5_{J6,J}$	Scaled mass (mass/2π), in grams, of fragments in the Jth weight range in the polar zone J6.
M6(37,J9)	$M6_{J6,J}$	Average weight of fragments, in grains, in the Jth weight group in polar zone J6.

Table AIII - continued

Variable and Dimensions	Finite Difference Notation	Description
Q6(37,J9)	$Q6_{J6,J}$	Fraction in the Jth weight group of the number of fragments weighing more than one grain in polar zone J6.
M(J9)	M_J	Weight (grains) at the left end point of the Jth fragment weight interval.
M1(2L1+K1)	M'_{M5}	Value of $\bar{M}$, the average weight of fragments weighing more than one grain, assigned to metal mass point M5.
W6(2L1+K1)	$W6_{M5}$	Total scaled mass (mass/2π) of fragments from the metal mass point M5.
A9(2L1+K1)	$A9_{M5+1/2}$	Polar angle of direction of fragments from the midpoint of the line joining metal mass points M5 and M5+1 (degrees).
Q3(2L1+K1)	$Q3_{M5}$	Velocity of metal mass point M5 (cm/μsec).
W8(36)	$W8_{J2}$	Total scaled mass (mass/2π), in grams, of fragments in polar zone J2.
W9(36)	$W9_{J2}$	Sum of velocities times masses contributed to polar zone J2.
Y(36)	Y_{J2}	Average fragment velocity in polar zone J2 (ft/sec).
N8(37)	$N8_{J6}$	Total number of fragments weighing more than one grain in polar zone J6.
Y8(37)	$Y8_{J6}$	Number of steradians in the J6th polar zone.
Y9(37)	$Y9_{J6}$	Number of fragments, weighing more than one grain, per steradian in the J6th polar zone.

Table AIV

Input Statements - Fragment Prediction Code

Statement Number	Symbol	Description
1110	J9	Number of fragment weight ranges.
1120	T7	The fluid dynamics print routine and fragment prediction routine are entered every T7 microseconds.
1130	T4	Maximum time.
1140	T1	Initial time step.
1150	E8	Factor for maximum time step increase.
1160	N4	The fragment prediction routine is bypassed for cycle numbers less than N4.
1170	N5	Number of times fluid dynamics print routine and fragment prediction routines are entered.
1180	N6	Maximum cycle number.
1190	N7	Counter for N5.
1200	K4	The inert fuze material ends and the HE starts at K=K4+1.
1210	R2	Fuze material density (grams/cc).
1220	R4	Metal casing density (grams/cc).
1230	C3	Constant in artificial viscosity formula.
1240	E7	Cut off.
1250	D1	Arena radius, in ft.
1270	R0	Radial coordinate of arena center (cm).
1280	Z0	Axial coordinate of arena center (cm).
1290	L1	Maximum L in computation grid.

Table AIV - continued

Statement Number	Symbol	Description
1300	K1	Maximum K in computation grid.
8760	D	Detonation velocity.
8770	D2	Equation of state constant.
8780	R3	Density of undetonated HE (ρ_o).
8790	D3	Equation of state constant.
8800	D4	Equation of state constant.
8810	E1	Energy released by HE (mbar-cc/original cc).
8820	F1	Equation of state constant.
8830	F2	Equation of state constant.
8840	Q3	$1-V1_{cj}$ (where $V1_{cj}$ is the relative specific volume at the Chapman Jouguet state.
1520	Z(K1,0)	Initial axis position of inside of metal at the base (cm).
1530	Z(0,0)	Initial axis position of outside of metal at the nose (cm).
1540	Z(1,0)	Initial axis position of inside of metal at the nose (cm).
1550	Z(K1+1,0)	Initial axis position of outside of metal at the base (cm).
1610	Z(K,0)	Input special (K,0) values (cm).
1620	R(K,L1), R(K,L1+1)	Input R(K,L1), R(K,L1+1) coordinates of metal casing (in cm). This can be done with subroutines 9910 or 9960. The data is entered in 22670-22700.
1650	R(K,L1), R(K,L1+1)	Input special R(K,L1) amd R(K,L1+1) values, if necessary.

Table AIV - continued

Statement Number	Symbol	Description
1750	Z(K1,L)	Input special (K1,L) values, if necessary; for example, when the inside of the base is curved.
3560	W(K,L)	Special coding for base end metal masses. Subroutine 8910 is useful when the inside of the base is straight. It makes the change shown in Fig.A3. Subroutine 9110 can be used, with appropriate values of the coordinates, when the inside of the base is curved. Here, the lines separating the areas assigned to the mass points, as in Fig.3.
21210	M(J)	Read in left endpoints of the J9 weight intervals in grains. The data are inserted in 22710.
21220	M1(M5)	Read in the assigned value of $\bar{M}$, the average weight of fragments weighing more than one grain, for each metal mass point M5. The data are inserted in 22720-22740. At the outset, if these data are not available, the beginning of the program can be run with the statement 3855 - GO TO 30000. This will stop the program after the values of χ (Eq.(80)) have been calculated. These values can be used to get the values of $M1_{M5}(=\bar{M})$ from Fig.10 or a similar plot. After these values of $M1_{M5}$ are inserted in 22720-22740, remove the EXIT card 3855 and start over. If desired some of the initial printout and the χ computation can now be bypassed with 1815 - GO TO 1880, 3620 - GO TO 3860.

Table AV

Output Statements -- Fragment Prediction Code

Statement Number	Description
1310	HE density ρ_e (=R3 here), internal energy E1(mbar-cc/orig.cc) and equation of state constants.
1320-1370	K1, L1, K4, J9, T7, T4, T1, E8, N5, N6, E7, R2, R4, R0, Z0, D1 (see Table AIV for descriptions.)
1820-1870	Case dimension input - (bypass with 1815 GO TO 1880)
3630-3680	Initial coordinates of zone centers ($Z1_{K,L}$, $R1_{K,L}$) and scaled masses (masses/2π) $W1_{K,L}$ associated with zones (bypass with 3625 - GO TO 3690).
3700-3750	Initial coordinates of grid points and scaled masses (masses/2π) $W_{K,L}$ assigned to grid points and metal mass points (bypass with 3695 - GO TO 3760).
3800	Initial axial position, $Z^{*}_{K,0}$, initial inside radius (cm), C/M, and χ ($in^{4/3}$) (see Eq. (80)). (Bypass both the computation and the printout with 3675 - GO TO 3860.)
4340	N, T, and K3 are printed out here for each cycle.
6610	N, T, T1, and T2 are printed out whenever the fluid dynamics print routine is entered.
6660-7070	Fluid dynamics print routine. Prints F_K, metal velocity (ft/sec), $Z_{K,L}$ (cm), $R_{K,L}$ (cm), $U_{K,L}$(cm/μsec), $V_{K,L}$ (cm/μsec) $P2_{K,L}$(= P1+Q1) (mbar), $Q1_{K,L}$ (mbar), $V1_{K,L}$ (cc/cc), $E2_{K,L}$ (mbar-cc/orig.cc), $T3_{K,L}$ (μsec), $C2_{K,L}$ [(cm/μsec)^2], $R3_K$ (cm), $Z3_K$ (cm), $P3_K$ (mbar), $K9_K$, $R4_K$ (cm), $Z4_K$ (cm), $S8_K$. Bypass with 6640 - GO TO 7080.

Table AV - continued

Statement Number	Description
8670-8740	Diagnostic printout if $C2_{K,L} < 0$.
8850-8880	HE and equation of state data. Called in 1310.
9750-9810	Diagnostic printout if $J > K1-1$ in the mass point pressure routine.
10520	Diagnostic printout before exit, if J=K1 in slide routine.
11690	Energy check printout. Gas internal energy, gas kinetic energy, metal kinetic energy, and total energy are printed out. These should be compared with their values at T=0, called for in 4090.
11930-11950	Metal mass point velocities (ft/sec) on the ends (lines K=1 and K=K1, for L=3 to L1-1). These are called for in 7020).
20890	Mass point number M5, polar zone J6, weight of metal from mass point M5 in polar zone J6 (grains).
20990	Total metal weight, in pounds and grains.
21130	Polar zone J2, weight of metal in polar zone J2 (grains), percent of total weight of metal in polar zone J2, average velocity in polar zone J2 (ft/sec).

Table AV - continued

Statement Number	Description
21680	Mass point number M5, corresponding K and L, total scaled mass (mass/2π, in grams) associated with M5, polar angle $Aq_{M5+1/2}$ for fragments from midpoint of line segment joining M5 and M5+1.
21730-21750	Input data $\bar{M}$ (= $M1_{M6}$) vs M5 ($\bar{M}$ is given in grains).
22030-22260	Number of fragments, in each weight range, in each polar zone.
22290-22470	AMSAA lethal area input. The average weight in grains and the fraction of the total number of fragments in the polar zone are printed out for each fragment weight range in each polar zone. Also Y(J6), the initial velocity (ft/sec) for the polar zone (this is the average fragment velocity in the zone (see statement no. 21120), Y9(J6) the number of fragments per steradian in the polar zone, and the average fragment weight (grains) in the polar zone. The latter quantity is not called for by the AMSAA lethal area program.
22480-22660	Calculated quantities needed by the JMEM lethal area program are stored on tape, for use by a FORTRAN program (Table AVI) which prepares the appropriate card deck.

TABLE A-VI FORTRAN ROUTINE FOR PREPARATION OF CARD DECK FOR INPUT TO JMEM LETHAL AREA PROGRAM *

```
      PROGRAM PCARD(TAPE1,PUNCH,TAPE6=PUNCH,INPUT=65,OUTPUT=65)
      DIMENSION A(7)
      DATA FMT/8H(7F10.4)/
      REWIND 1
 10   CONTINUE
C CALLS A SPECIAL VERSION OF GCARD TO READ FROM TAPE1 INSTEAD OF INPUT
      CALL GCARD(1,7,A(1),A(2),A(3),A(4),A(5),A(6),A(7))
      IF(A(6).EQ.1.E36) CALL GCARD(1,2,A(6),A(7))
      PRINT 100,A(7)
      WRITE(6,100) A
 100  FORMAT(7F10.4)
 105  NDATA=A(7)
      IF((NDATA.EQ.0).OR.(A(7).EQ.1.E36)) GO TO 200
      CALL BASICR(7,NDATA,FMT)
      CALL BASICR(7,NDATA,FMT)
      GO TO 10
 200  PRINT 201,A
 201  FORMAT(* ERROR ON INPUT *,7F10.4)
      GO TO 10
      END
      SUBROUTINE BASICR(NP,NDATA,FMT)
      DIMENSION A(19)
      A(19)=1.E36
      INUM=0
      K=1
 10   IF(INUM.GE.NDATA) RETURN
      CALL GCARD(1,12,A(K),A(K+1),A(K+2),A(K+3),A(K+4),A(K+5),A(K+6),
     +A(K+7),A(K+8),A(K+9),A(K+10),A(K+11))
      IE=K+11
      DO 110 I=K,IE
      IF(A(I).EQ.1.E36) GO TO 120
 110  CONTINUE
      I=K+12
 120  I=I-1
      INUM=INUM+I
      IF(I.LT.NP) GO TO 140
      IF((INUM.GE.NDATA).AND.(I.EQ.NP)) GO TO 140
 125  WRITE(6,FMT)(A(K),K=1,NP)
      IF(I.EQ.NP) GO TO 150
      IS=NP+1
      DO 130 K=IS,I
      A(K-NP)=A(K)
 130  CONTINUE
      I=I-NP
      IF(I.GE.NP) GO TO 125
C HAVE LESS THAN NP DATA FROM LAST CARD AND LEFTOVERS
 135  K=I+1
      IF(INUM.EQ.NDATA) GO TO 145
      INUM=INUM-I
      GO TO 10
C HAVE LESS THAN NP ON ONE CARD
 140  IF(INUM.LT.NDATA) GO TO 135
 145  IE=MIN0(I,NDATA+I-INUM)
      WRITE(6,FMT)(A(K),K=1,IE)
      RETURN
 150  I=0
      GO TO 135
      END
```

*This routine was written by C.B.Wilson (NOL/CODE332)