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INPUT RESEARCH AND TESTING OF CODE TOODY

G. A. Haynie

DEVELOPMENT DIVISION

July - September 1971

For
Systems Division, Department 112

MASTER

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Section Y

DISCLAIMER

INPUT RESEARCH AND TESTING OF CODE TOODY

The purpose of this report is to simplify and further explain input instructions for Code TOODY and to demonstrate the ability of the code to reproduce cylinder test results. This input is intended to be a supplement to, and not a replacement for, the existing TOODY manual. The TOODY manual should be read and understood before attempting to read this report.

Problems arise in the preparation of the input data in four areas: material definition, initial shape definition, the restart feature, and the limiting of output. Aside from these areas, the code is adequately discussed in the manual, "TOODY, A COMPUTER PROGRAM FOR CALCULATING PROBLEMS OF MOTION IN TWO DIMENSIONS."[a]

The material definition tells the program what position each material will occupy. Each material has a number, a minimum and maximum I value, and a minimum and maximum J value. The material numbers are as follow:

MAT NUMBER	MEANING
0	Empty Space
1	Material #1
2	Material #2
.	.
.	.
.	.
10	Material #10
11	Free Boundary
12	Applied Stress Boundary
13	Symmetry Plane Boundary
14	Fixed Boundary

Material numbers one through ten are the materials used in the problem and are supplied by the user. Numbers eleven through fourteen are boundary conditions which are supplied by the program.[b] Any material used must be completly surrounded by boundary meshes. Meshes referred to on no card will retain the value MAT = 0 indicating that they are outside the problem. To define the position each material will occupy, one first gives the program the material number. Then by giving the program the values i_s, i_e, j_{so}, j_{si}, j_{eo}, and j_{ei} which stand for minimum and maximum I values, the minimum J value and its multiplying factor, and the maximum J value and its multiplying factor respectively. With these values the program can define the position of every mesh needed to represent each material by using the following double nested loop.

---

[a] *B. J. Thorne and W. Herrmann, Sandia Report No. SC-RR-66-602, July 1971.*

[b] *IBID, "Boundary Conditions," p. 52 - 54.*

DØ 100 $I = i_s, i_e$

$$j_s = j_{so} + j_{si} * I$$

$$j_e = j_{eo} + j_{ei} * I$$

DØ 100 $J = j_s, j_e$

100 MAT (J, I) = K

If one wants the material to be rectangular, j_{si} and j_{ei} should be set to zero. If the variables j_{si} and j_{ei} are given a value, it causes the material to be stairstepped. In setting up the material definition, it is sometimes useful to have a scaled drawing of the figure. With the scaled drawing, one can very easily pick off the I MAX and I MIN and the J MAX and J MIN values of each material and boundary condition used.

The initial shape definition goes along very closely with the material definition. The material definition projects the object into j,i - space, while the initial shape definition gives dimensions to the object. The program uses a variable called ISET to determine the type of coordinates to be used. If ISET = 1, rectangular coordinates are used and i indexes along the z axis (axis of abscissas) and j indexes along the x axis, (axis of ordinates). If ISET = 2, polar coordinates are used and i indexes along a radius vector while j indexes angular increments. If ISET = 3, polar coordinates are again used with the roles of i and j interchanged. If one uses ISET = 1, the problem shown in Fig. 1 could be set up in this manner. The lower left-hand corner becomes the origin for X_o, Z_o, I_o, and J_o for all materials as long as the mesh size in both the X and Z directions is constant. With the mesh size constant, the values for X_o, Z_o, I_o, and J_o at the origin becomes 0, 0, 1, and 1 respectively. The variables A_x and A_z have the roles of Δ X and Δ Z. Deciding on a mesh size of 0.1 by 0.1, the values of A_x and A_z both become 0.1 in all materials. By having a scaled drawing such as Fig. 1, one can pick z, x points off the figure and use the equations:

EQUATION SET I

$$a_{j,1} = z_o + a_z (i - i_o) + b_z (i - i_o)(j - j_o) + f(j,i) + k_z(j - j_o)$$

$$x_{j,i} = x_o + a_x (j - j_o) + [b_x + c_x (j - j_o)] (z - z_o) + g(j,i,z) - k_x(i - i_o).$$

where f(j,i) is taken to be

$$f(j,i) = \begin{cases} 0 \text{ if } & i \leq i_o \\ 1/2\, c_z (i - i_o)(i - i_o - 1) \text{ if } & i > i_o \end{cases}$$

while $g(j,i,z) = d_x(z - z_o)^2$.

One can then form a system of linear equations in Z and X and solve them for the variables b_x, c_x, d_x, k_x, b_z, c_z, d_z, and k_z. As long as the meshes are rectangular, all of these variables become zero. In Fig. 1, if material 2 is taken to be impacting on materials 1 and 3, we would have an initial component velocity of u^x and $u^z = 0$ for materials 1 and 3, while material 2 would have an initial component velocity of $u^x = 0$ and $u^z = -v$, where v is the velocity of impact. In this manner, we have been able to define all the materials needed to set up the initial shape definition for Fig. 1. If we decide to change mesh sizes in any one direction, such as in Fig. 2, where we have doubled the size of the meshes in the X direction for materials 1 and 3 and doubled the mesh size in both the X and Z direction for material 2, one should go about setting up the shape definition in the same manner as before with one exception. The mesh size is no longer constant in the Z direction, and it is necessary to have a new origin for every change in mesh size. For materials 1 and 3 the origin is still at $X_o = Z_o = 0$ and $I_o = J_o = 1$, but for material 2 the origin becomes $X_o = .4$, $Z_o = .8$, $I_o = 9$, and $J_o = 3$.

This puts the origin at a point which is in the same relative position to material 2 as the first origin was to materials 1 and 3. When using ISET = 2 or 3, one follows the same general procedure using the following equations:

EQUATION SET II

$$R = r_o = r_1 + r_2(i - i_o - 1) \quad (i - i_o)$$

$$x_{j,i} = R \sin (\omega_o + (j - j_o)\, \omega_1) + x_o$$

$$z_{j,i} = R \cos (\omega_o + (j - j_o)\, \omega_1) + z_o$$

$$u^x = u^r \sin (\omega_o + (j - j_o)\, \omega_1)$$

$$u^z = u^r \cos (\omega_o + (j - j_o)\, \omega_1).$$

The variables r_0, r_1, r_2, u^r, ω_0 , and ω_1 assume the roles of a_x, b_x, c_x, u^x, and a_x, and b_z respectively.

Caution must be used in limiting computer run time and output of Code TOODY. The activity test is one way of limiting computer run time. This test first causes the program to perform calculations only on the meshes specified by IACT in the first time cycle. After the first cycle, the program uses PACT or minimum pressure and checks to see if the pressure is greater than or equal to the minimum pressure. If it is, the program increases the value of IACT to the i value of the mesh to allow the shock wave to move to the next column. If the minimum pressure is greater than the mesh pressure, then the program doesn't perform any calculations on the rest of the meshes. It is also desirable to use the minimum meshes needed to adequately represent the problem of the 2260 meshes provided by the program. This not only cuts down on the run time but it has been found that over-zoning often produces unreliable answers. The program also has a restart feature which can be used to break up a long run into several shorter runs. However, at the time this report was written the restart feature would not reproduce answers received from one long run when broken up into several shorter runs using the restart feature. In order to limit the number of printed pages, it has been found that it is better to look at just a portion of the problem rather than the whole problem. For every column asked for there will be at least a page of output depending on how many rows asked for as there are two lines printed for every row. If the user is interested in seeing more columns than rows, he can set alpha = 0 and interchange the roles of X and Z. In doing so, the user is also interchanging the roles of pages and lines per page and thus cutting down on pages of output. The user should pick his minimum and maximum edit times carefully. One must remember that at every time increment between the minimum and maximum edit times, one will get at least a page for every column asked for depending on how many rows are asked for by the user. If one were to ask for the printout of just five columns at twenty-five time increments one would have at least 125 pages of output.

The main reason for researching Code TOODY was to find out how well the code could reproduce two dimensional test results. The one inch cylinder test was chosen as a problem for TOODY to reproduce. The code was able to reproduce the CJ Pressure to within two percent using LX-04-1 as the HE in the cylinder. Two cylinder shots of LX-04-1, P108-4-21-1 LOT 92-5 and P108-7-3-1 LOT 92-9 were used as measured values for comparison to Code TOODY's answers. In both cases the wall movement as predicted by TOODY reproduced the measured values very closely as shown in Table II. If the code is able to reproduce all tests as well as it reproduced the cylinder test, it will, at worse, give the user a starting value so he will know if he is obtaining reasonable experimental results. If the user gets good agreement with his measured values, the code will provide further insight into the test by showing him the roles artificial viscosity, stress, and energy play in the test, values that would be difficult to measure experimentally.

Also included in this report are Appendix A which has input instruction for Code TOODY, Appendix B, which contains some of the material and HE constants needed by the code, and Appendix C which contains operating instructions and listing of a short Wang 700-B program used in analyzing the results from TOODY.

1 - Material No. 1
2 - Material No. 2
3 - Material No. 3
4 - Free Boundary
5 - Symmetry Plane Boundary

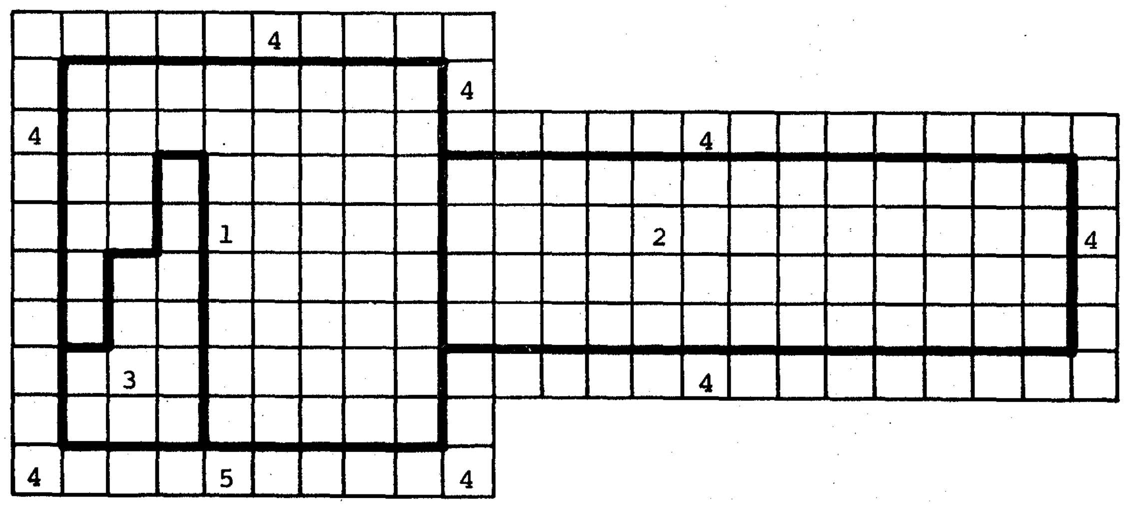

FIG. 1

1 - Material No. 1
2 - Material No. 2
3 - Material No. 3
4 - Free Boundary
5 - Symmetry Plane Boundary

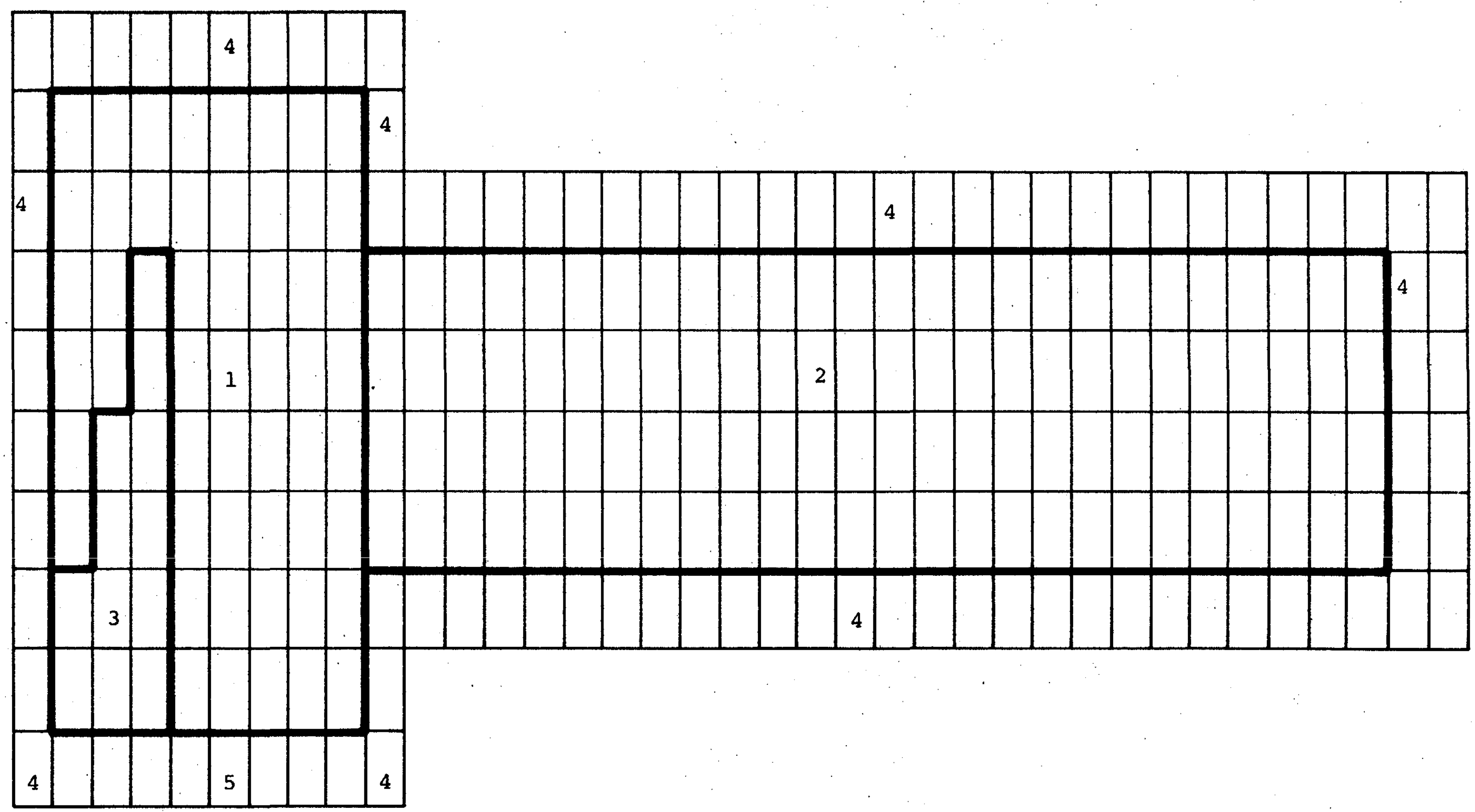

FIG. 2

Table I

P 108-4-21-1 Lot 92-5

&

P 108-7-3-1 Lot 92-9

Lot 92-5 X	T Average	Lot 92-0 X	T Average
0.0	0.0299	0.0	-0.0727
0.50	0.5694	0.50	0.5765
1.00	1.0597	1.00	1.1085
1.50	1.5105	1.50	1.5672
2.00	1.9299	2.00	1.9809
2.50	2.3244	2.50	2.3674
3.00	2.6996	3.00	2.7374
3.50	3.0597	3.50	3.0967
4.00	3.4083	4.00	3.4485
4.50	3.7482	4.50	3.7945
5.00	4.0815	5.00	4.1353
5.50	4.4098	5.50	4.4714
6.00	4.7345	6.00	4.8029
6.50	5.0564	6.50	5.1303
7.00	5.3760	7.00	5.4541
7.50	5.6939	7.50	5.7746
8.00	6.0103	8.00	6.0923
8.50	6.3253	8.50	6.4077
9.00	6.6389	9.00	6.7212
9.50	6.9512	9.50	7.0330
10.00	7.2622	10.00	7.3434
10.50	7.5718	10.50	7.6524
11.00	7.8799	11.00	7.9601
11.50	8.1866	11.50	8.2665
12.00	8.4917	12.00	8.5714
12.50	8.7953	12.50	8.8750
13.00	9.0974	13.00	9.1770
13.50	9.3981	13.50	9.4777
14.00	9.6973	14.00	9.7770
14.50	9.9952	14.50	10.0750
15.00	10.2918	15.00	10.3719
15.50	10.5873	15.50	10.6678
16.00	10.8818	16.00	10.9629
16.50	11.1752	16.50	11.2572
17.00	11.4678	17.00	11.5509
17.50	11.7597	17.50	11.8441
18.00	12.0509	18.00	12.1366
18.50	12.3416	18.50	12.4286
19.00	12.6317	19.00	12.7199
19.50	12.9214	19.50	13.0104
20.00	13.2108	20.00	13.3001
20.50	13.4997	20.50	13.5888
21.00	13.7883	21.00	13.8766
21.50	14.0766	21.50	14.1636
22.00	14.3645	22.00	14.4498
22.50	14.6521	22.50	14.7354
23.00	14.9393	23.00	15.0208
23.50	15.2262	23.50	15.3060
24.00	15.5126	24.00	15.5912
24.50	15.7985	24.50	15.8765
25.00	16.0840	25.00	16.1618

Table II

X CALC. (MM)	T CALC. (μsec)	Lot 92-9 X MEAS. #1 (MM)	Lot 92-9 REL. ERR. #1 (%)	Lot 92-5 X MEAS. #2 (MM)	Lot 92-5 REL. ERR. #2 (%)
0.00	0.000	-	-	-	-
0.29	0.553	0.482	39.82	.458	40.18
0.73	1.013	0.910	19.77	.952	23.35
1.18	1.496	1.396	15.49	1.457	19.03
1.81	2.018	2.048	11.62	2.112	14.29
2.41	2.473	2.643	8.82	2.698	10.67
3.14	3.019	3.392	7.42	3.434	8.81
3.83	3.501	4.075	6.02	4.136	7.41
4.58	3.497	4.797	4.53	4.873	6.02
5.42	4.551	5.620	3.57	5.717	5.20
6.11	5.004	6.307	3.13	6.419	4.81
7.02	5.578	7.193	2.41	7.318	4.07
7.77	6.048	7.931	2.02	8.060	3.60
8.55	6.527	8.690	1.61	8.822	3.08
9.36	7.018	9.476	1.22	9.607	2.57
10.19	7.517	10.282	0.89	10.411	2.13
11.00	8.003	11.070	0.63	11.201	1.79
11.79	8.472	11.838	0.40	11.968	1.48
12.74	9.030	12.757	0.13	12.888	1.15
13.66	9.575	13.662	0.02	13.796	0.98
14.39	10.000	14.368	0.15	14.508	0.81
15.28	10.515	15.242	0.25	15.378	0.63
16.14	11.013	16.085	0.34	16.224	0.51
16.98	11.497	16.908	0.42	17.050	0.41
17.96	12.059	17.868	0.51	18.014	0.30
18.75	12.513	18.644	0.57	18.795	0.24
19.68	13.043	19.557	0.63	19.710	0.15
20.43	13.474	20.301	0.64	20.455	0.12
21.32	13.982	21.183	0.65	21.336	0.07
22.19	14.480	22.054	0.62	22.201	0.05
23.20	15.050	23.051	0.65	23.293	0.03
24.05	15.533	23.893	0.66	24.036	0.06

APPENDIX A

APPENDIX A

INPUT INSTRUCTIONS FOR CODE TOODY[a]

Set I Main Control Parameters

Card 1   Format (9A8)

Run Identification

Card 2   Format (15I5)

IMAX[b]	Maximum of i index	
JMAX	Maximum of j index	
NOMAT	No. of materials involved	
ALPHA	Symmetry indicator	
IDELOUT	Usually set equal to 1	BINARY TAPE OUTPUT PARAMETERS (IDELOUT through ISPEC)
JDELOUT	Usually set equal to 1	
IOPSW	Initial value output switch, IF IOPSW = 0, switch is "off" and if IOPSW ≠ 0, switch is "on"	
NTAP	No. of first output tape used	
NTLIM	No. of last output tape used	
IPRINT	Print switch, if IPRINT = 0 print switch is "off" and if IPRINT ≠ 0 print switch is "on"	
ISPEC	Special subroutine switch, ISPEC = 0 switch is "off" and ISPEC ≠ 0 switch is "on"	
IACT	Starting valve of activity test indicator	
IECSW	Energy check switch, IECSW = 0 switch is "off" and IECSW ≠ 0 switch is "on".	
IRSSW	Write restart tape switch, IRSSW = 0 switch is "off" and IRSSW ≠ 0 switch is "on".	
IRRSSW	Read restart tape switch, IRRSSW = 0 switch is "off" and IRRSSW ≠ 0 switch is "on".	

Card 3   Format (7E 10.3)

PMAX	Maximum allowable pressure	
TMAX	Maximum run time (in problem time)	
K_{t1}	Stability Coefficient, usually equal to 1	
OUTMIN	Minimum output time	BINARY TAPE OUTPUT PARAMETERS (OUTMIN through PACT)
OUTMAX	Maximum output time	
DELOUT	Output time increment	
PACT	Minimum allowable pressure	

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[a] *IBID, Appendix C, Input Instruction, pp. 93-106.*

[b] *Variables are listed in order of occurrence on card.*

Card 4a Format (6E 10.3)

B_1	Viscosity coefficient, usually equal to 1.2
B_2	Viscosity coefficient, usually equal to 0.06
B_3	Viscosity coefficient, usually equal to 0.4
B_4	Viscosity coefficient, usually equal to 0.02
K_{t2}	Maximum initial time step
K_{t3}	Maximum rate of increase in time step, usually equal to 1.1

Card 4b Format (3E10.3, 7I5)

This card is present only if IPRINT ≠ 0

TPMIN	Minimum edit time	PRINTOUT PARAMETERS
TPMAX	Maximum edit time	
TPDEL	Edit time increment	
IPMAN	Starting column for printing	
IPMAX	Ending column for printing	
IPDEL	Column increment	
JPMIN	Starting row for printing	
JPDEL	Row increment	
MAXMIN	If MAXMIN = 1, minimum and maximum values of some variables are printed at the end of the run, MAXMIN = 2, only pressure values are calculated, and MAXMIN = 0, feature is bypassed	

Card 4c Format (3E10.3, 4X, 6I5)

This card is present only if ISPEC ≠ 0

TSMIN
TSMAX
TSDEL
ISMIN
ISMAX
ISDEL
JSMIN
JSMAX
JSDEL

These variables are designed to function in the same manner as the variables on card 4b; however, only the first three are handled in the main program so that the remaining six can have any function desired in the special subroutine

Card 4d Format (2E10.3, I5)

This card is present only if IECSW ≠ 0

EPE	Relative energy allowable
ECON	Value of E_R below which no energy check will be made
NSYCLE	Reference cycle

Card 4e   Format (2E10.3)

This card is present only if IRRSW $\neq$ 0 or IRRSW $\neq$ 0

RSTIME   No. of minutes to allow before restart tape is written
IGNORRSE   if IGNORRSE = 0, then an error on reading the restart tape will cause termination

Set II Material Definition

Each material used requires this Material Definition Card.

Card 1   Format (7I5)

MAT	Material or boundary type
i_s	Minimum column
i_e	Maximum column
j_{so}	Minimum row constant coefficient
j_{sl}	Minimum row linear coefficient
j_{eo}	Maximum row constant coefficient
j_{el}	Maximum row linear coefficient

Card 2   Format (10A8)

END OF MATERIAL DEFINITION
This card should be placed after all of the material definition cards

Card 2a   Format (2E10.3)

This card is present after the above END CARD if MAT = 12 is present in any of the Material Definition Cards.

P_o	$P = P_o \exp(\beta t)$
β	Exponential rate factor in above equation

Set III Equation of State Constants

A set of Equation of State Constant Cards must be read for each material in order of increasing NOMAT or material numbers.

Card 1   Format (1I5)

IES(MAT) Number of equation of state to be used for material number MAT

Equation of State Number 1

Card 1 Format (7E10.3)

P_o	Initial material density
C_o	Bulk sound speed
-	Not used
P_{MIN}	Minimum pressure
TDEP	Energy deposit time, if TDEP <0 no energy is added, TDEP = 0 all the energy is added on the first cycle, and TDEP >0 energy is deposited over the first 100 cycles.
ν	Poisson's ratio
-	Not used

Card 2 Format (I10, 6E10.3)

NOK	No. of K's, NOK = 0 the equation $PH = \frac{P_o C_o \eta}{(1-S\eta)^2}$ is used, NOK $\geq$ 1 the equation $pH = K_o\eta\ (1 + k_1\eta + k_2\ \eta_2 + \ldots)$, including K_o
-	Not used
K_1 or s	If NOK = 0 this term is the s in the above equation. If NOK $\geq$ 2 then this is the K in the second equation.
K_2	Coefficient of the second equation
K_3	Coefficient of the second equation
K_4	Coefficient of the second equation
K_5	Coefficient of the second equation

Card 3 Format (I10, 6E10.3)

NOH	No. of terms, including Γ_o, in the equation $\Gamma = \Gamma_o$ $(1 + h_1\eta + h_2\eta\ + \ldots)$
Γ_o, h_1, h_2, h_3, h_4, h_5	Coefficients in the above equation

Card 4 Format (ILO, 6E10.3)

NOG	NOG = 0 uses the equation $G = \frac{3(1 - 2\nu)}{2(1 - \nu)}\ K$, NOG 1 uses the equation $G = G_o(1 + g_1\eta + \ g\ \eta^2 + g_z\eta^2 + \ldots)$, including G_o
	Not used
g_1, g_2, g_3, g_4, g_5	Coefficients in the second equation

Card 5 Format (I10, 6E10.3)

NOY	Chooses the yield strength to be used by the problem[4]
Y_o, Y_1, Y_2	Coefficients of equations chosen by NOY
-, -, -	Not used

Equation of State Number 2
High explosive equation of state

Card 1 Format (6E10.3)

c_o	Initial density
c_o	Bulk sound speed
D	Detonation wave velocity
γ	Ratio of specific heats
B5	Wave width constant
-	Not used

Card 2 Format (I10, 2E10.3)

ND	Detonation option, ND = 1 detonation occurs along constant z, ND = 2 detonation occurs along a constant x, ND = 3 detonation occurs along the line $x = x_d$ and $z - z_d$, and ND = 4 initiation occurs uniformly throughout the explosive
X_d	X coordinate of detonation point
Z_d	Z coordinate of detonation point

It is possible to add equation of state numbers 3 through 6 if necessary for some problems.[5]

Set IV Initial Shape of Definition

These cards are needed for each material in order of increasing material number.

Card 1 Format (I5)

ISET ISET = 1, rectangular coordinates
ISET = 2, polar coordinates
ISET = 3, polar coordinates, interchanges the roles of i and j in ISET = 2

[4] *IBID, See Pages 30 through 32*

[5] *IBID, page 104*

Card 2 Format (8E10.3)

x_o	Initial X position
a_x or r_o	Coefficients in the Equations Set I or Set II
b_x or r_1	
c_x or r_2	
d_x	
j_o	Initial j value
u^x	Initial velocity in the x direction
k_x	Coefficient in Equation Set I

Card 3 Format (8E10.3)

z_o	Initial Z position
a_z or ω_o	Coefficients in the equations Set I or Set II
b or ω_1	
c_z	
d_z	
i_o	Initial i value
u^z	Initial velocity in the z direction
k_z	Coefficient in Equation Set I

APPENDIX B

APPENDIX B

This compendium has been composed to simplify the finding of constants used by several hydro-codes. Many of the constants in this compendium are at best estimates of the actual values; therefore, they should be used more as a starting point rather than an absolute value. All values given are in the centimeter-gram-microsecond system.

AIR CONSTANTS

Initial Material Density	.001292 g/cm^3
Bulk Sound Speed	.033528 cm/μs
Minimum Pressure	0
Poisson Ratio	NA
NOK	0
S	NA
NOH	NA
Γ_o	NA
NOG	0
NOY	1
Ratio of Specific Heats	1.4

AL CONSTANTS

Initial Material Density	2.71 g/cm^3
Bulk Sound Speed	.538 cm/μs
Minimum Pressure	0.0 M bars
Poisson Ratio	.333
NOK	0
S	1.345
NOH	1
Γ_o	2.1
NOG	0
NOY	1

BRASS CONSTANTS

Initial Material Density	8.45 g/cm^3
Bulk Sound Speed	.378 cm/μs
Minimum Pressure	0
Poisson Ratio	.33
NOK	0
S	1.434
NOH	

Γ_o	2.04
NOG	0
NOY	1

CU COEFFICIENTS (99+ PURE)

Initial Material Density	8.9 g/cm^3
Bulk Sound Speed	.392 cm/μs
Minimum Pressure	-.0015 M bars
Poisson Ratio	.333
NOK	0
S	1.4
NOH	1
Γ_o	2.04
NOG	0
NOY	1

H_2O CONSTANTS

Initial Material Density	1.0 g/cm^3
Bulk Sound Speed	.148 cm/μs
Minimum Pressure	0
Poisson Ratio	0
NOK	0
S	1.85
NOH	1
Γ_o	.28
NOG	0
NOY	1
Sublimation Energy	.0244 g/cm^3

INERT TNT

Initial Material Density	1.63 g/cm^3
Bulk Sound Speed	.257 cm/μs
Minimum Pressure	0.0 M bars
Poisson Ratio	.29
NOK	0
S	2.05
NOH	1
Γ_o	1.57
NOG	0
NOY	1

IRON CONSTANTS

Initial Material Density	7.86 g/cm^3
Bulk Sound Speed	.377 cm/μs
Minimum Pressure	0
Poisson Ratio	.26
NOK	0
S	1.92
NOH	1
Γ_o	1.46
NOG	0
NOY	1

STEEL CONSTANTS

Initial Material Density	7.84 g/cm^3
Bulk Sound Speed	.367 cm/μs
Minimum Pressure	0
Poisson Ratio	.26
NOK	0
S	1.92
NOH	1
Γ_o	1.46
NOG	0
NOY	1

HE CONSTANTS FOR BARATOL

Initial HE Density	2.55 g/cm^3
Bulk Sound Speed	.204 cm/μs
Detonation Wave Velocity	.487 cm/μs
Ratio of Specific Heats	3.32
Wave Width Constant	2.5

HE CONSTANTS FOR COMP B-3
40/60 TNT/RDX

Initial HE Density	1.75 g/cm^3
Bulk Sound Speed	.271 cm/μs
Detonation Wave Velocity	.805 cm/μs

Ratio of Specific Heats	2.95
Wave Width Constant	2.5

HE CONSTANTS FOR HMX

Initial HE Density	1.90 g/cm^3
Bulk Sound Speed	.251 cm/μs*
Detonation Wave Velocity	.910 cm/μs
Ratio of Specific Heats	3.03
Wave Width Constant	2.5

HE CONSTANTS FOR LX-04-01

Initial HE Density	1.86 g/cm^3
Bulk Sound Speed	.274 cm/μs
Detonation Wave Velocity	.847 cm/μs
Ratio of Specific Heats	2.83
Wave Width Constant	2.5

HE CONSTANTS FOR LX-07-0

Initial HE Density	1.88 g/cm^3
Bulk Sound Speed	.251 cm/μs*
Detonation Wave Velocity	.866 cm/μs
Ratio of Specific Heats	2.86**
Wave Width Constant	2.5

**Average of known bulk sound speeds, which range from .204 cm/μs to .286 cm/μs.*

***An approximate CJ Pressure was used in obtaining the Ratio of Specific Heats from the equation*

$$\gamma = \frac{10\rho_0 D^2}{P_{CJ}} - 1$$

HE CONSTANTS FOR LX-10

Initial HE Density	1.86 g/cm^3
Bulk Sound Speed	.251*
Detonation Wave Velocity	.822 cm/μs
Ratio of Specific Heats	2.859
Wave Width Constant	2.5

HE CONSTANTS FOR OCTOL
75/25 TNT/HMX

Initial HE Density	1.82 g/cm^3
Bulk Sound Speed	.240 cm/μs
Detonation Wave Velocity	.848 cm/μs
Ratio of Specific Heats	2.82
Wave Width Constant	2.5

HE CONSTANTS FOR PBX-9010

Initial HE Density	1.78 g/cm^3
Bulk Sound Speed	.251 cm/μs*
Detonation Wave Velocity	.837 cm/μs
Ratio of Specific Heats	2.80
Wave Width Constant	2.5

HE CONSTANTS FOR PBX-9011

Initial HE Density	1.785 g/cm^3
Bulk Sound Speed	.251 cm/μs*
Detonation Wave Velocity	.852 cm/μs
Ratio of Specific Heats	3.00
Wave Width Constant	2.5

**Average of known bulk sound speeds, which range from .204 cm/μs to .286 cm/μs.*

HE CONSTANTS FOR PBX-9205

Initial HE Density	1.69 g/cm^3
Bulk Sound Speed	.274 c/μs
Detonation Wave Velocity	.824 cm/μs
Ratio of Specific Heat	2.98
Wave Width Constant	2.50

HE CONSTANTS FOR PBX-9404

Initial HE Density	1.851 g/cm^3
Bulk Sound Speed	.286 cm/μs
Detonation Wave Velocity	.8841 cm/μs
Ratio of Specific Heats	2.86
Wave Width Constant	2.5

HE CONSTANTS FOR PBX-9407

Initial HE Density	1.60 g/cm^3
Bulk Sound Speed	.251 cm/μs*
Detonation Wave Velocity	.791 cm/μs
Ratio of Specific Heats	2.92**
Wave Width Constant	2.5

HE CONSTANTS FOR PENTOLITE 50/50
50/50 TNT PETN

Initial HE Density	1.66 g/cm^3
Bulk Sound Speed	.223 cm/μs
Detonation Wave Velocity	.747 cm/μs
Ratio of Specific Heats	2.86*
Wave Width Constant	2.5

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* *Average of known bulk sound speeds, which range from .204 cm/μs to .286 cm/μs.*

** *An approximate CJ Pressure was used in obtaining the Ratio of Specific Heats from the equation*

$$\gamma = \frac{10\rho_0 D}{P_{CJ}} - 1$$

HE CONSTANTS FOR PETN

Initial HE Density	1.70 g/cm^3
Bulk Sound Speed	.251 cm/μs*
Detonation Wave Velocity	.830 cm/μs
Ratio of Specific Heats	2.84
Wave Width Constant	2.5

HE CONSTANTS FOR RDX

Initial HE Density	1.77 g/cm^3
Bulk Sound Speed	.251 cm/μs*
Detonation Wave Velocity	.864 cm/μs
Ratio of Specific Heats	2.91
Wave Width Constant	2.5

HE CONSTANTS FOR TETRYL

Initial HE Density	1.71 g/cm^3
Bulk Sound Speed	.251 cm/μs*
Detonation Wave Velocity	.785 cm/μs
Ratio of Specific Heats	3.21**
Wave Width Constant	2.5

HE CONSTANT FOR TNT

Initial HE Density	1.63 g/cm^3
Bulk Sound Speed	.239 cm/μs
Detonation Wave Velocity	.693 cm/μs
Ratio of Specific Heats	2.56
Wave Width Constant	2.5

**Average of known bulk sound speeds, which range from .204 cm/μs to .286 cm/μs.*

***An approximate CJ Pressure was used in obtaining the ratio of specific heats from the equation*

$$\gamma = \frac{10\rho_0 D}{P_{CJ}} - 1$$

APPENDIX C

APPENDIX C

A small program was written for the Wang calculator Model 700-B to search through a table of measured distances and times. When given a time the program will interpolate for a distance which it takes to be X_{meas}. The program is then given X_{calc} and by using the two X values the program calculates the relative error. The table values must be stored in registers 8 through 107 with the first fifty of these registers containing distance values and the second fifty registers containing the time values. By putting the end program command at step 950, one can record all Table values onto tape and thus save them for future use. The X_{meas} values and the relative errors in Table II were obtained by using this program and two cylinder shot tables 92-5 and 92-9. Operation instructions and listing follow.

INTERPOLATOR AND RELATIVE ERROR DETERMINER

OPERATING INSTRUCTIONS

Prime
Rewind
Tape Ready
Load Program
(1) Key in Time
Go
(2) Key in X (Distance)
Go

Repeat steps (1) and (2) for all values desired
Output will be in the form

TIME	INTERPOLATED VALUE	RELATIVE ERROR

PROGRAM LISTING

000	04	08	MARK
001	07	09	9
002	04	04	ST DIR
003	00	06	06
004	07	08	8
005	06	04	↑
006	04	08	MARK
007	07	00	0
008	07	05	5
009	07	00	0
010	06	00	+
011	05	05	Re IN DIR
012	04	04	ST DIR
013	00	02	02
014	07	05	5
015	07	00	0
016	06	01	−
017	05	05	Re IN DIR
018	04	04	ST DIR
019	00	03	03
020	07	05	5
021	07	01	1
022	06	00	+
023	05	05	Re IN DIR
024	04	04	ST DIR
025	00	04	04
026	07	05	5
027	07	00	0
028	06	01	−
029	05	05	Re IN DIR
030	04	04	ST DIR
031	00	05	05
032	04	14	ST DIR Y
033	00	07	07
034	04	15	Re DIR Y
035	00	06	06
036	05	07	SKIP Y $\geq$ X
037	04	07	SEARCH
038	07	01	1
039	04	15	Re DIR Y
040	00	07	07
041	04	07	SEARCH
042	07	00	0
043	04	08	MARK
044	07	01	1
045	04	05	Re DIR
046	00	03	03
047	04	01	− DIR
048	00	05	05
049	06	01	−
050	04	05	Re DIR
051	00	05	05
052	06	03	÷
053	04	05	Re DIR
054	00	02	02
055	04	01	− DIR
056	00	04	04
057	04	05	Re DIR
058	00	04	Re DIR
059	06	02	X =
060	04	05	Re DIR
061	00	02	02
062	06	00	+
063	04	05	Re DIR
064	00	06	06
065	04	12	WR σ
066	01	08	0108
067	01	02	0102
068	04	13	END α
069	04	11	WRITE
070	07	07	0707
071	06	05	↓
072	04	11	WRITE
073	07	07	0707
074	05	15	STOP
075	06	06	↓↑
076	06	01	−
077	06	03	÷
078	06	05	↓
079	06	07	1 x 1
080	04	11	WRITE
081	07	07	0707
082	05	15	STOP
083	04	07	SEARCH
084	07	09	9
950	05	12	END

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