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DYNAMIC RESPONSE OF MISSILE STRUCTURES TO IMPULSIVE LOADS CAUSE--ETC(U)

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Technical Report AEC-TR-76-01

DYNAMIC RESPONSE OF MISSILE STRUCTURES TO
IMPULSIVE LOADS CAUSED BY NUCLEAR EFFECTS BLOWOFF

by

Thomas L. Cost

June 1976

Final Report On

Contract DAAH01-76-C-0293

Prepared for

Ground Equipment and Materials Directorate
US Army Missile Research
Development and Engineering Laboratory
US ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA 35809

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Two dynamic structural analysis computer codes have been developed for the analysis of missile type structures subjected to impulsive loads produced by nuclear effects blowoff. One code, IMPLATE, is applicable to flat plate structures prestressed by inplane mechanical and thermal loads and the other code, IMPSHELL, can be applied to thin cylindrical shell type structures preloaded by internal pressure. The impulsive loads are calculated with the aid of a photoelectric energy deposition code,		

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20. ABSTRACT (Continued)

KNISH, and a blowoff model. A theory for correlating the nuclear effects blowoff impulse with impulse produced by a laboratory simulation exploding foil technique is presented.

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1. INTRODUCTION

During a nuclear engagement outside the atmosphere a severe threat to the structural integrity of missile structures is posed by the x-ray component of the radiant energy emission from a nuclear weapon detonation. When the levels of absorbed energy are sufficiently high, sublimation of the outer structural surface can occur with a resulting impulsive load being imparted to the structure. This impulsive load can produce stress waves in the structure or gross structural response or both. Although the influence of the stress waves on structural integrity has been studied widely (1-3), the influence of the impulsive loads on the longer-time structural response has received less attention (4,5).

The objective of this project was to develop an ability to study the structural response of isotropic, metallic, flat plate and cylindrical structures subjected to impulsive loads produced by x-ray induced material sublimation. It is assumed in this study that the material remains elastic and that the x-rays damage the structure by decreasing the structural thickness where sublimation occurs. Temperature influence on material properties is neglected for simplicity.

To accomplish this objective, a flat plate structural response code, QTRPLATE, used in experimental studies at the U.S. Army Missile Command (6) was modified to accommodate x-ray deposition loads and a cylindrical shell code, IMPSHELL, developed for predicting structural response to such loads.

2. IMPULSIVE LOAD CALCULATION

The radiant energy component of a nuclear weapon detonation can sublimate the surface layer of structures exposed to the energy flux provided the fluence is sufficiently high. This extremely rapid sublimation can produce impulsive loads on the structure due to the momentum transfer resulting from the rapid movement of the surface particles. The impulsive loads induce structural motion and associated stresses, strains, and deformations.

2.1 General Computational Method

The Whitener (11) analytical model has been incorporated into both the flat plate and circular cylinder structural response codes described in Sections 3. and 4., respectively. The Whitener model requires a knowledge of the energy deposition profile through the thickness of the exposed structure along with appropriate physical properties. The model can be expressed as

$$I_B = \sum_{j=1}^n (\rho \Delta x)_j \sqrt{2F_c (H - E_s)_j} \quad (2.1)$$

where:

I_B = blowoff impulse*, taps/cm²

ρ_j = density of zone j, g/cm³

Δx_j = thickness of zone j, cm

H_j = total energy deposited in zone j, cal/g

E_s = sublimation energy for the material, cal/g

n = number of zones

F_c = conversion factor, 4.186×10^7 ergs/cal

$(H - E_s)_j$ = excess energy in zone j

* A tap is 1 bar - microsecond.

To implement this model the distribution of the deposited energy through the thickness of the structure must be known.

2.2 KNISH Computer Code

The KNISH photon deposition computer program (7) used to compute the energy deposition profiles for use in the Whitener model has evolved from a code written by Dr. John Huntington at the Moleculon Company for the Defense Atomic Support Agency (DASA) in 1968. The code was modified by the Physics International Company in 1972. The code treats Compton single scattering and photoelectric energy deposition in an axisymmetric slab geometry.

The input-output operations of the KNISH code have been modified for use in the codes described here to make data input more concise and to permit direct use of the output in the Whitener model for impulse calculations. The following simplifications have been made in data input:

- 1) the spectrum energy mesh is computed internally by a prescribed formula which takes into account the characteristic temperature of the nuclear weapon detonation,
- 2) only spectra formed by superimposing individual blackbody spectra are permitted,
- 3) the number of regions in the structure is preset to one,
- 4) the number of dose points is set internally in the code to fifty.

This information is provided to relate the simplifications made in KNISH input procedures to the original code described in Reference 7. Data input descriptions for the flat plate code `IMPLATE` and cylindrical shell code `IMPSHELL` are described in Sections 3.3 and 4.3, respectively.

The accuracy of KNISH was investigated by comparing the accuracy of energy deposition profiles computed with KNISH with standard results.

Such a comparison for copper is illustrated in Figure 2.1 for various blackbody temperatures. As can be seen from the figure, good accuracy is obtained using KNISH for all blackbody temperatures. The printed output from KNISH for this case is contained in Table 2.1.

2.3 Flat Plate Model

As illustrated in Figure 2.2, the radiant energy striking the flat plate is assumed to occur normal to the plate and be uniformly distributed. For purposes of impulse calculation the plate is assumed divided into various regions or zones through the thickness. These zone descriptions are preset in KNISH and used to calculate the energy deposition profile. From a knowledge of this profile the thickness of the sublimated layer is determined by noting where in the structure the deposited energy intensity exceeds the sublimation energy. All material absorbing energy at levels higher than the sublimation energy will be sublimated. This condition is illustrated schematically in Figure 2.3.

Once the deposition profile and thickness of the sublimated layer is determined, the Whitener model, Eq. 2.1, can be used to compute the total impulse in taps per cm^2 . The impulse is assumed imparted to the structure by a uniform pressure load which varies linearly with time as illustrated in Figure 2.4, where t_s , the "shine time", is input as data. The maximum pressure P is computed by use of the equation

$$P = 2I_B/t_s \quad (2.2)$$

where I_B is computed using Eq. 2.1.

2.4 Cylinder Model

Radiant energy is assumed to impinge on the cylindrical shell model as indicated in Figure 2.5a. Only the component of the energy normal to the surface is assumed to be absorbed in the cylindrical structure. This causes the resulting impulse to be imparted to the structure in a nonuniform manner as indicated in Figure 2.5b. The same procedure

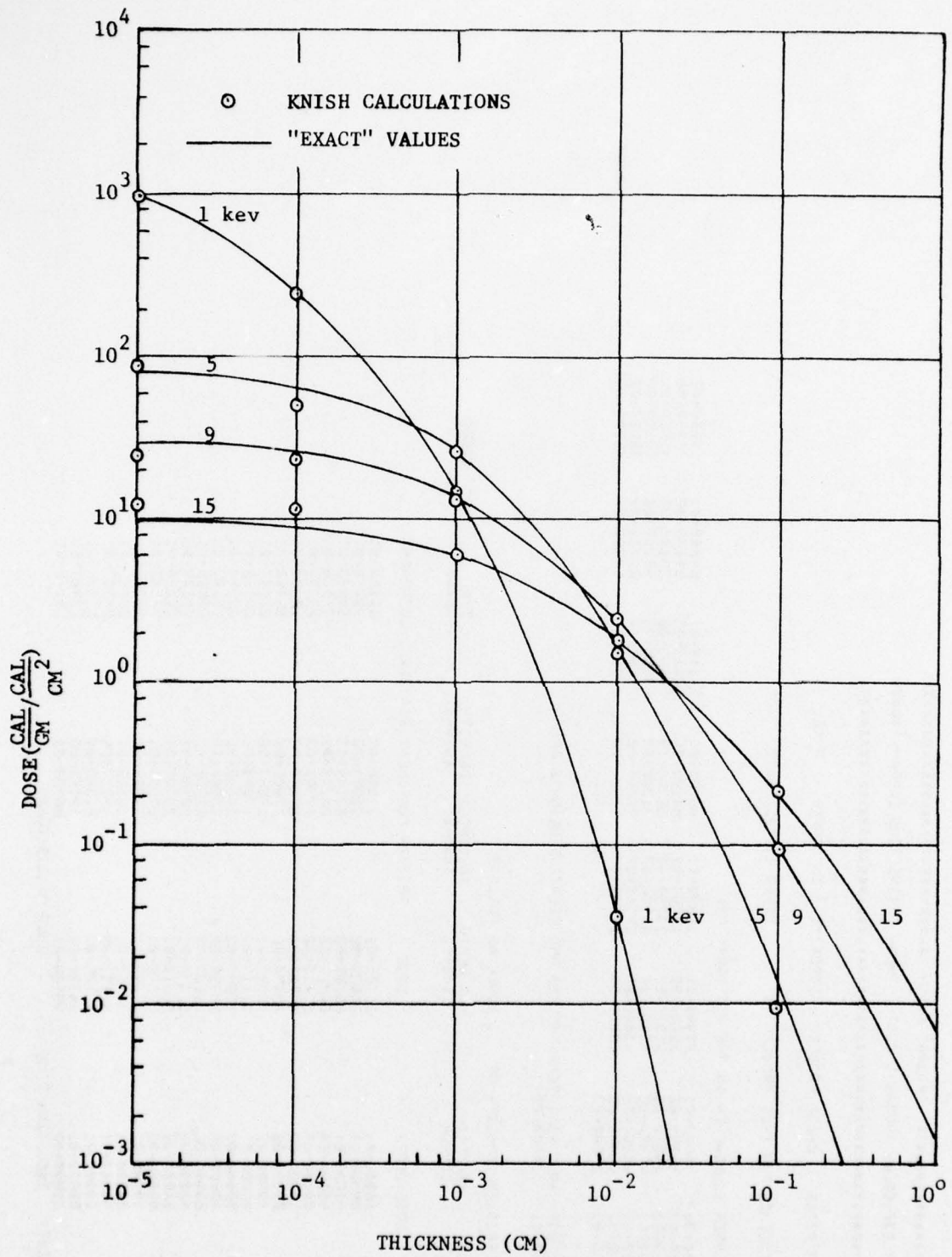


Figure 2.1. Energy Deposition in Copper

TABLE 2.1 ENERGY DEPOSITION IN COPPER

PROGRAM KNISH
 MODIFIED BY THOMAS L. COST, ATHENA ENGINEERING COMPANY 88888

CHECK PROBLEM - DEPOSITION IN COPPER - 9 KEY

THE FLUENCE FOR THIS PROBLEM IS 10000*01 CAL/CM2

THE UPPER BOUNDARIES ON THE HISTOGRAM ARE

90000+00	18000+01	27000+01	36000+01	45000+01	64500+01	84000+01	10350+02
12300+02	14500+02	16200+02	18150+02	20100+02	22050+02	24000+02	25950+02
27300+02	29500+02	31800+02	33750+02	35700+02	37650+02	39600+02	41550+02
42300+02	45500+02	47400+02	49350+02	51300+02	53250+02	55200+02	57150+02
59300+02	61650+02	63000+02	67500+02	72000+02	76500+02	81000+02	85500+02
90000+02	99000+02	108000+02	117000+02	126000+02	135000+02	144000+02	153000+02

BLACK BODY SPECTRUM TEMPERATURES AND RELATIVE WEIGHTS ARE

90000+01	10000+01
----------	----------

THIS PROBLEM CONSISTS OF 1 ZONES AS FOLLOWS

ZONE NO	MATERIAL	FAR DEPTH	THICKNESS	DENSITY	Z/A	NO EDGES
1	COPPER	1000+01	1000+01	8940+01	4560+00	30

DOSE DEPTH DOSE PRIMARY COMPONENT SCATTERED COMPONENT

10000-04	31721+02	31662+02	59180-01
20000-04	36623+02	36570+02	63710-01
40000-04	26208+02	26148+02	60663-01
60000-04	28219+02	28158+02	61506-01
80000-03	27413+02	27350+02	62258-01
10000-03	26703+02	26640+02	62933-01
20000-03	23874+02	23809+02	65452-01
40000-03	19922+02	19854+02	68062-01
60000-03	17117+02	17048+02	69158-01
80000-03	15003+02	14933+02	69554-01
10000-02	13365+02	13286+02	69583-01
20000-02	86660+01	85982+01	67828-01
40000-02	51338+01	50709+01	62840-01
60000-02	36314+01	35731+01	59254-01
80000-02	27872+01	27329+01	54246-01
10000-01	25433+01	24926+01	50732-01
20000-01	10550+01	10169+01	38049-01
40000-01	42693+00	40237+00	24557-01
60000-01	23125+00	21382+00	17436-01
80000-01	14330+00	13023+00	11066-01
10000+02	96163+01	86022-01	10146-01

NORMAL EXIT EXECUTION TIME 5962 MILLISECONDS

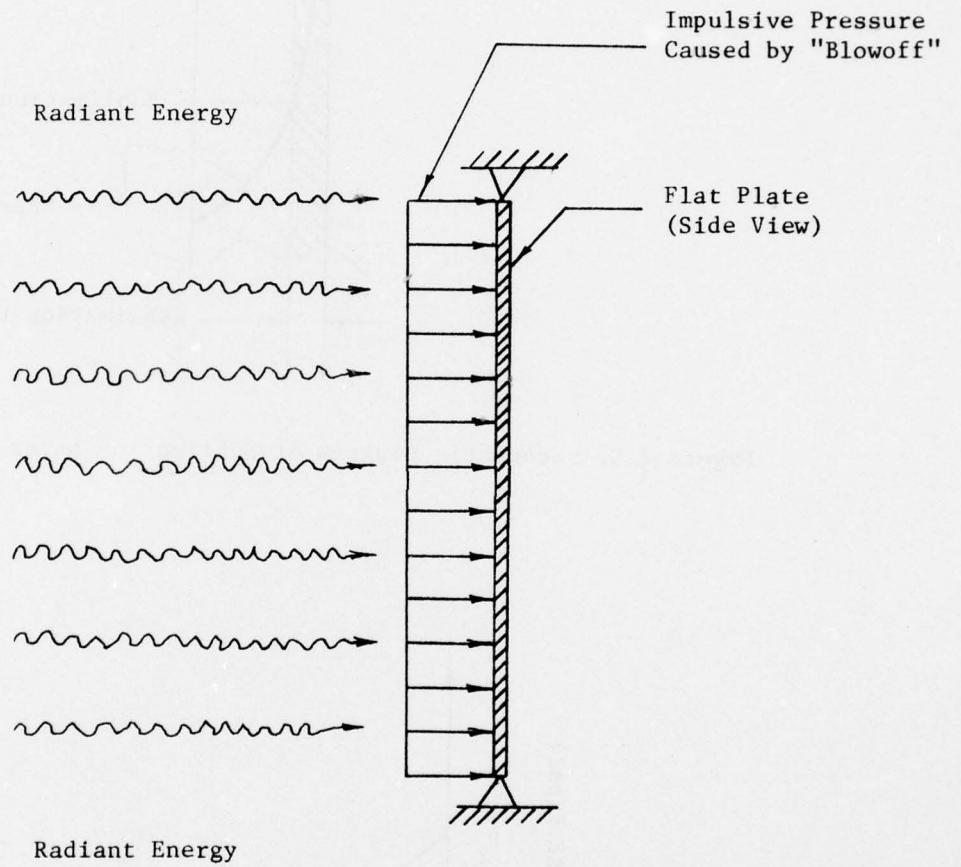


Figure 2.2. Schematic Diagram of Impulsive Loading of a Flat Plate

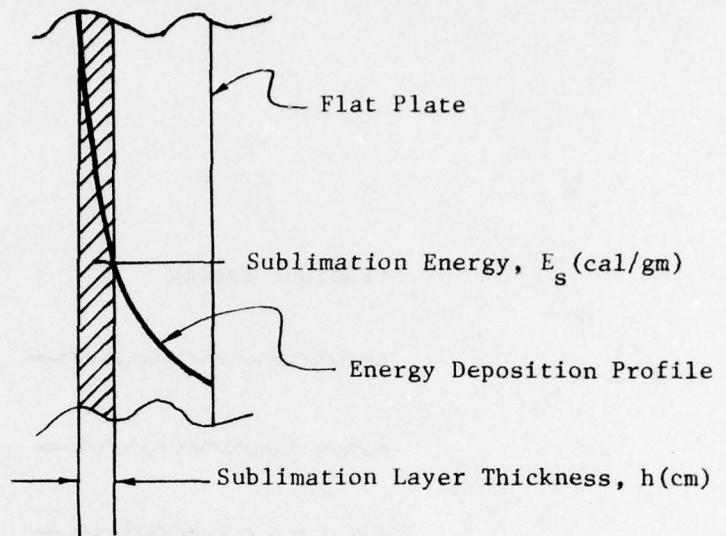


Figure 2.3. Schematic Diagram of Sublimation Layer in Flat Plate

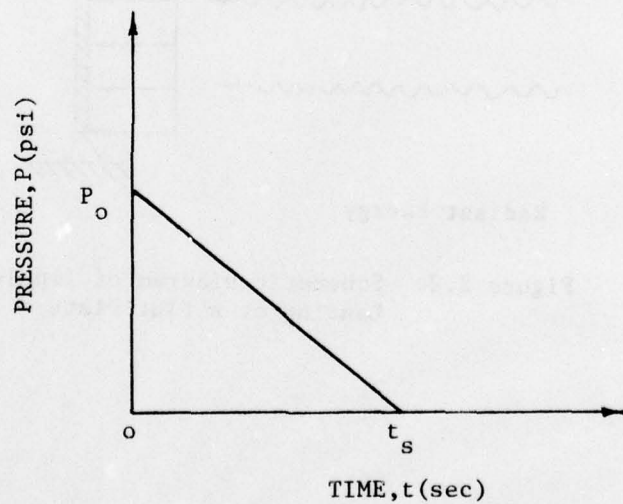
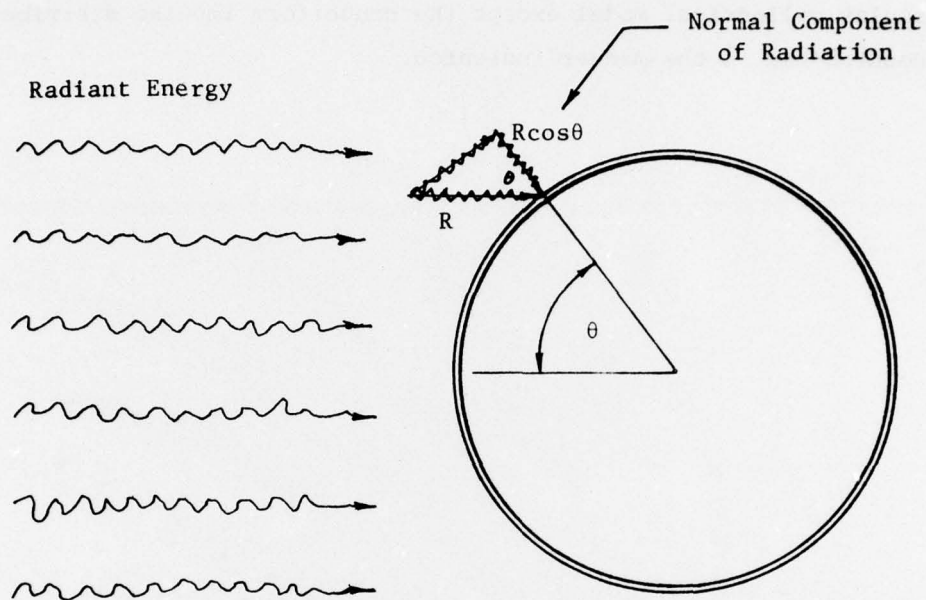
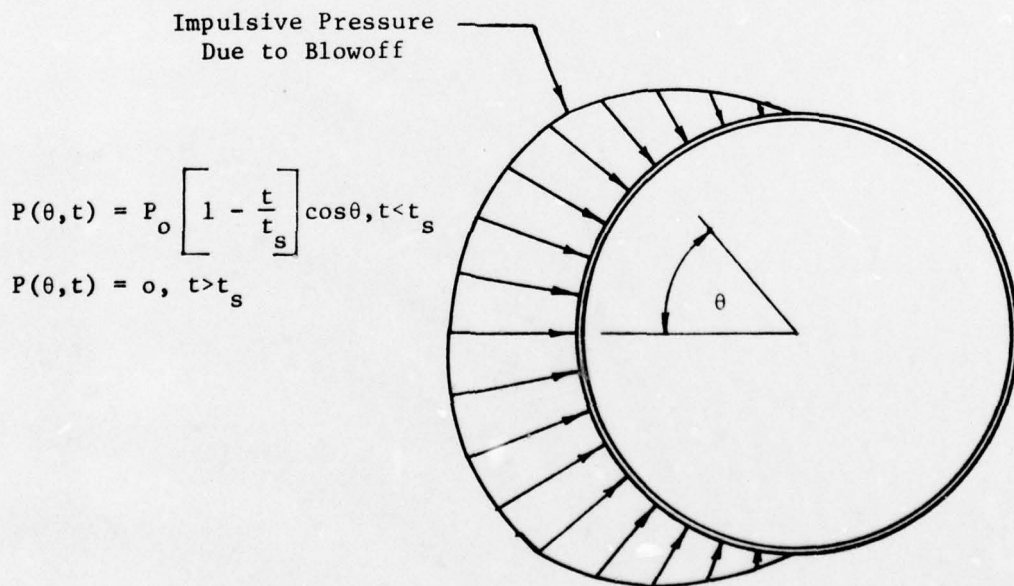


Figure 2.4. Time Variation of Blowoff Pressure



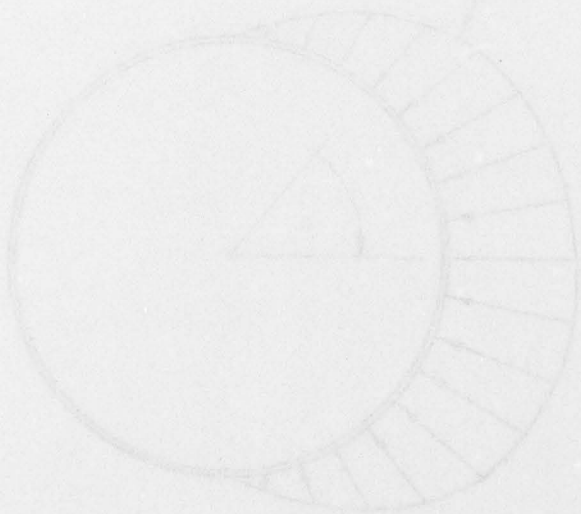
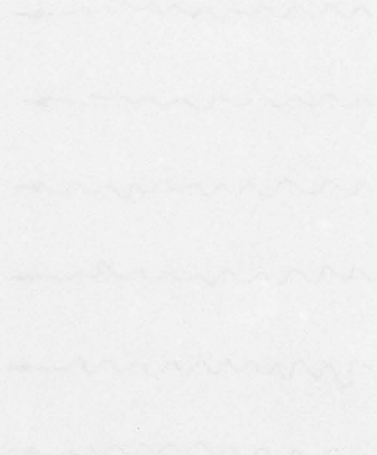
a) Exposure of Shell to Radiant Energy



b) Impulsive Pressure Distribution on Shell

Figure 2.5. Schematic Loading of Cylindrical Shell

used in the flat plate model to calculate the impulse is used for the circular cylindrical model except the nonuniform impulse distribution is accounted for in the manner indicated.



$$I(r) = \int_0^r I(r') r' dr'$$
$$I(r) = \frac{1}{2} I_0 r^2$$

3. FLAT PLATE RESPONSE CODE

3.1 Description

The computer code QTRPLATE, developed previous to this work (6), is designed to predict the dynamic response of flat plates to air blast loads while, simultaneously, prestressed by inplane thermal and mechanical loads. The code implements a finite difference solution to the governing equations of motion which are based upon small deformation theory and linear elastic material behavior. A mode superposition and shock spectrum approach is used to compute peak values for the stresses, strains, and displacements in the plate. Predicted response has been shown to agree closely with experimental results (8).

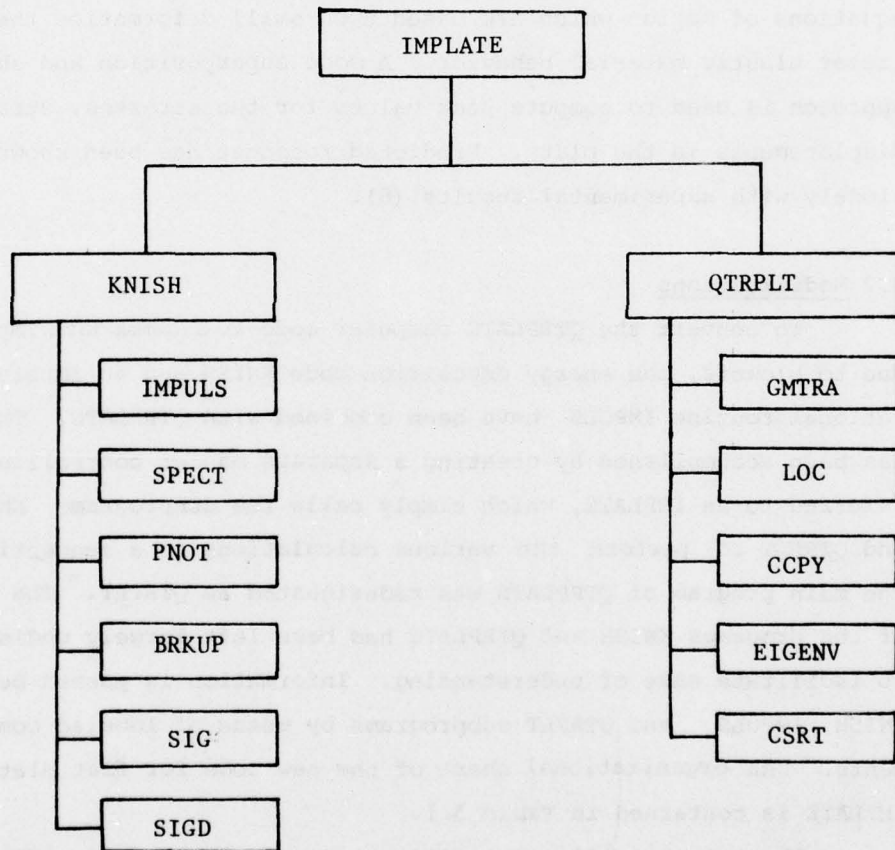
3.2 Modifications

To convert the QTRPLATE computer code to accommodate impulse loads due to blowoff, the energy deposition code KNISH and an impulse computational routine IMPULS have been combined with QTRPLATE. The combination has been accomplished by creating a separate master controlling program, referred to as IMPLATE, which simply calls the subprograms KNISH, IMPULS, and QTRPLT to perform the various calculations in a sequential manner. The main program of QTRPLATE was redesignated as QTRPLT. The integrity of the programs KNISH and QTRPLATE has been left largely undisturbed to facilitate ease of understanding. Information is passed between the KNISH, IMPULS and QTRPLT subprograms by means of labeled common statements. An organizational chart of the new code for flat plate response IMPLATE is contained in Table 3.1.

The most significant modification made to the code QTRPLATE involved modification of the subroutine SPCTRM. The displacement shock spectrum, defined for each generalized coordinate of the flat plate, is defined as (6),

$$F_i(\omega_i) = \max_{t>0} \left| \frac{1}{M_i \omega_i} \int_0^t P(\tau) \sin \omega_i(t-\tau) d\tau \right| \quad (2.3)$$

Table 3.1 ORGANIZATIONAL CHART FOR IMPLATE



where M_i is the generalized mass, ω_i the natural frequency associated with the i_{th} degree of freedom, and $P(t)$ is the pressure intensity. Using the expression for the pressure contained in Figure 2.4, the value for $F_i(\omega_i)$ can be expressed as

$$F_i(\omega_i) = \frac{P_o(2+t \omega_i)}{t M_i \omega_i^3} \quad (2.4)$$

The value of FMAX in subroutine SPCTRUM has been modified to reflect this change.

In addition to the above changes, minor modifications have been made in the input/output procedures. These changes will be described in the following section.

3.3 Data Input Format

Data is input to the computer code IMPLATE by specifying information on punched cards as follows:

1. Title card
2. Fluence card
3. Spectrum definition cards
4. Material identification card
5. Photoelectric cross-section cards
6. Plate geometry and edge restraint card
7. Material property card
8. Mechanical and thermal preload card

If several problems are to be run sequentially, cards 1 through 8 should be prepared for each problem and stacked sequentially. Normal termination of a run stream is accomplished by placing a card with the letters END in the first three columns at the end of the stacked deck. Details of the information to be specified in cards 1 through 8 above are contained in Table 3.2.

TABLE 3.2 DATA CARD DESCRIPTION FOR IMPLATE

Card	Columns	Format	Data Item
1	1-80	80A1	TITLE - Any alphanumeric characters chosen to describe problem
2	1-10	E10.0	FLOONZ - Fluence (cal/cm ²)
	11-12	E10.0	SHINET - "Shine time" (μs)
3	1-10	E10.0	TT - Blackbody temperature (kev)
	11-12	E10.0	FF - Decimal fraction of total fluence at temperature TT
			Repeat cards of type 3 for as many blackbody spectra needed (5 maxium). End cards with a blank card.
4	1-10	10A1	ZMAT - Material name
	11-20	E10.0	DD - Material density (g/cm ³)
	21-30	E10.0	ZZ - Ratio of atomic number to atomic weight
	31-40	I10	NED - No. of cards containing photoelectric cross-sections
	41-50	E10.0	ES - Sublimation energy (cal/gm)
5	1-10	E12.0	A1 - Coefficient in cross-section equation
	11-20	E12.0	B1 - Coefficient in cross-section equation
	21-30	E12.0	U - Upper photon energy limit
6	1-10	F10.0	A - Plate width (cm)
	11-20	F10.0	H - Plate thickness (cm)
	21-26	1A6	BC - Boundary conditions (CC or SS)
7	1-10	F10.0	E - Young's modulus (GN/m ²)
	11-20	F10.0	ANU - Poisson's ratio
	21-30	F10.0	ALPHA - Thermal expansion coefficient, (1/°F)
	31-40	F10.0	RHO - Plate density (g/cm ³)
8	1-10	F10.0	TX - x-tension (N/cm)
	11-20	F10.0	TY - y-tension (N/cm)
	21-30	F10.0	TEMP - temperature (°F)

3.4 Sample Problem

To illustrate the punched card format, consider the problem in which a square, aluminum plate, 10 X 10 X 0.16 cm is subjected to an inplane tension preload in the x-direction of magnitude 20 N/cm, an inplane tension preload in the y-direction of 10 N/cm, and is heated to a temperature 20°F above the reference state. Finally, the plate is subjected to a fluence of 75 cal/cm², from a nuclear weapon with a blackbody spectrum and a temperature of 5 kev. The shine time of the nuclear weapon is 300. microseconds. Young's modulus for the aluminum is 68.95 GN/m², Poisson's ratio is 0.3, the density 2.71 g/cm³, and the thermal expansion coefficient is 4.0x10⁻⁶/°F. The material photoelectric cross-section and atomic number properties are contained in Table 3.3. The plate is assumed to have all edges clamped. The data cards to run this problem are listed in Table 3.3.

The computer code IMPLATE computes the natural frequencies and mode shapes for the prestressed plate and uses these in a spectral analysis method to determine a conservative estimate of the maximum deflections, stresses, and strains in the plate. This information is printed out along with a description of the input data. The results of the sample problem described above are presented in Table 3.4.

PROGRAM IMPLATE
 DEVELOPED BY THOMAS L COST, ATHENA ENGINEERING COMPANY
 IMPLATE SAMPLE PROBLEM. 7079 AL PLATE. 75 CAL/CM2. 5 KEV BB

THE FLUENCE FOR THIS PROBLEM IS 75000+02 CAL/CM2

THE UPPER BOUNDARIES ON THE HISTOGRAM ARE

5000+00	1000+01	1500+01	2000+01	2500+01	3500+01	4500+01	5750+01
8333+01	7917+01	8000+01	1000+01	1167+02	1225+02	1333+02	1447+02
1500+02	1653+02	1767+02	1875+02	1933+02	2091+02	2200+02	2303+02
2407+02	2550+02	2633+02	2747+02	2850+02	2958+02	3067+02	3175+02
3233+02	3391+02	3500+02	3750+02	4000+02	4250+02	4500+02	4750+02
5000+02	5500+02	6000+02	6500+02	7000+02	7500+02	8000+02	8500+02
9000+02	15000+03						

BLACK BODY SPECTRUM TEMPERATURES AND RELATIVE WEIGHTS ARE

50000+01	10000+01
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THIS PROBLEM CONSISTS OF 1 ZONES AS FOLLOWS

ZONE NO	MATERIAL	AL 7079	DOSE	FAR DEPTH	1000+00	THICKNESS	DENSITY	Z/A	NO EDGES
1						1000+00	2700+01	4814+00	30

PRIMARY COMPONENT SCATTERED COMPONENT

DOSE DEPTH	DOSE	PRIMARY COMPONENT	SCATTERED COMPONENT
10000-04	31890+04	31852+04	46577+01
20000-04	32505+04	32055+04	46750+01
30000-04	32831+04	32184+04	46908+01
40000-04	32978+04	32251+04	47054+01
50000-04	33044+04	32287+04	47189+01
60000-04	33061+04	32293+04	47315+01
70000-04	33065+04	32291+04	47434+01
80000-04	33055+04	32280+04	47546+01
90000-04	33030+04	32259+04	47653+01
10000-03	32785+04	32070+04	47755+01
12000-03	32529+04	31851+04	47948+01
14000-03	32285+04	31604+04	48127+01
16000-03	32074+04	31425+04	48295+01
18000-03	31978+04	31330+04	48454+01
20000-03	31931+04	31303+04	48605+01
22000-03	31927+04	31300+04	48758+01
24000-03	31941+04	31315+04	48888+01

Table 3.4 OUTPUT FROM IMPLATE SAMPLE PROBLEM (continued)

BEST AVAILABLE COPY

BEST AVAILABLE COPY

54	26000-03	29020-04	21900-04	49022-01
55	20000-03	21020-04	21577-04	49150-01
56	30000-03	21800-04	21201-04	49275-01
57	32000-03	20000-04	20848-04	49395-01
58	34000-03	20500-04	20517-04	49512-01
59	36000-03	20250-04	20295-04	49635-01
60	38000-03	19911-04	19911-04	49755-01
61	40000-03	19602-04	19633-04	49843-01
62	42000-03	18400-04	18431-04	50342-01
63	50000-03	17517-04	17487-04	50789-01
64	70000-03	16710-04	16655-04	51193-01
65	80000-03	16033-04	15981-04	51562-01
66	90000-03	15430-04	15397-04	51990-01
67	10000-02	14910-04	14823-04	52310-01
68	20000-02	11640-04	11635-04	64304-01
69	30000-02	98610-03	98667-03	55268-01
70	40000-02	26378-03	25816-03	55695-01
71	50000-02	77130-03	76575-03	55858-01
72	60000-02	69760-03	69217-03	55867-01
73	70000-02	63690-03	63151-03	54817-01
74	80000-02	58670-03	58088-03	54562-01
75	90000-02	54161-03	53650-03	53851-01
76	10000-01	59321-03	49791-03	52977-01
77	20000-01	28364-03	27893-03	46156-01
78	30000-01	18954-03	18548-03	46155-01
79	40000-01	13020-03	13570-03	35942-01
80	50000-01	10840-03	10528-03	32061-01
81	60000-01	8770-02	8487-02	28583-01
82	70000-01	7870-02	7624-02	25354-01
83	80000-01	6160-02	5920-02	22800-01
84	90000-01	5850-02	5680-02	19314-01
85	10000-00	4550-02	4400-02	15141-01

IMPULSE DESCRIPTION

SUBLIMATION LAYER THICKNESS (CM) •
 IMPULSE (TAPS) •
 IMPULSE (N-MICROSECONDS/MS) •
 MAXIMUM PRESSURE (N/MS) •

00002000
 4 00753045
 400753 04200878
 2671 00099068

Table 3.4 (continued)

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DYNAMIC RESPONSE OF AN ELASTIC SQUARE PLATE
PRESTRESSED BY MECHANICAL AND THERMAL LOADS AND SUBJECTED
TO AN EXPONENTIALLY DECAYING BLAST LOADING

IMPLATE SAMPLE PROBLEM. 7079 AL PLATE. 75 CAL/CM2. 5 KEU DB

A (X-WIDTH) * 100000 M
 THICKNESS * 001000 M
 BOUNDARY CONDITIONS * CC
 MODULUS * 6894999616 N/M2
 POISSON RATIO * 3000
 THERMAL COEF * 0000040 1/DEGREES F
 DENSITY * 0000027100 KG/M3
 TENSION-X * 1999999993 N/M
 TENSION-Y * 0999999996 N/M
 TEMPERATURE * 20 00 DEGREES F
 PRESSURE * 2671 00695 N/M2
 TIME CONSTANT *
 THE NUMBER OF MODES CONSIDERED * 6

Table 3.4 (continued)

	REAL EIGENVALUES	FREQUENCIES IN CPS
142		
143		
144		
145	24766433+00	39101790+08
146	26804920+01	12879496+09
147	28885742+01	12898899+09
148		
149	75491892+01	21614330+09
150		
151	93119614+01	24065580+09
152		
153	93647850+01	24073571+09
154		
155	15979933+02	31446990+09
156		
157	1600736+02	31470403+09
158		
159	17404882+02	32819137+09
160		
161	17602244+02	33004688+09
162		
163	26372529+02	40398711+09
164		
165	26429686+02	40442485+09
166		
167	32059961+02	44542348+09
168		
169	44211874+02	52307152+09
170		
171	44280228+02	52347572+09
172		
173	58937926+02	60393338+09
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Table 3.4 (continued)

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213
214
215
END DATA

IN-PLATE SAMPLE PROBLEM. 7070 AL PLATE. 75 CAL/CM. 5 KEU 30

STRAIN, STRESS, AND DISPLACEMENT FOR MIDLINE STATIONS

NODE	STATION COORDINATE	X-STRAIN (CM/CM)	Y-STRAIN (CM/CM)	KV-STRAIN (CM/CM)	X-STRESS (N/CM ²)	Y-STRESS (N/CM ²)	KV-STRESS (N/CM ²)	DISPLACEMENT (IN)
1	012	- 872-05	408-05	000	- 852+07	- 778+07	000	419-05
2	025	746-05	103-04	000	- 708+07	- 693+07	000	103-04
3	037	148-04	154-04	000	- 641+07	- 637+07	000	149-04
4	050	178-04	175-04	000	- 614+07	- 615+07	000	166-04
5	062	148-04	154-04	000	- 641+07	- 637+07	000	149-04
6	075	746-05	103-04	000	- 708+07	- 693+07	000	103-04
7	087	- 972-05	408-05	000	- 852+07	- 778+07	000	419-05

Table 3.4 (continued)

4. CYLINDRICAL SHELL RESPONSE CODE

4.1 Description

A computer code, designated as IMPSHELL, has been developed to predict the dynamic response of a linear, elastic cylindrical shell to an impulsive load produced by "blowoff". The cylindrical shell can be subjected to an internal pressure. A finite difference approximate solution method is used to solve the governing equations of motion. The code IMPSHELL uses a different solution technique from the technique used in IMPLATE. Whereas the mode superposition method is used in IMPLATE, a Newmark-Beta (12) time intergration procedure is used in IMPSHELL. This permits an exact determination of the transient response of the shell to be computed for comparison with experimental data.

4.2 Equations of Motion

Applying the principle of virtual displacements to the shell structure illustrated in Figure 4.1 permits the governing equations of motion of the cylindrical shell in the v and w directions to be expressed as

$$\begin{aligned} R(p-q)(v-w,_{\theta}) + N_{\theta, \theta}(R + v,_{\theta} + w) + \\ + N_{\theta}(v,_{\theta\theta} + 2w,_{\theta} - v) = \rho h R^2 \ddot{v} \end{aligned} \quad (4.1)$$

and

$$\begin{aligned} R(p-q)(R+v,_{\theta}+w) + N_{\theta}(w,_{\theta\theta} - 2v,_{\theta} - w - R) + \\ + N_{\theta, \theta}(w,_{\theta} - v) = \rho h R^2 \ddot{w} \end{aligned} \quad (4.2)$$

$q = \text{external pressure}$

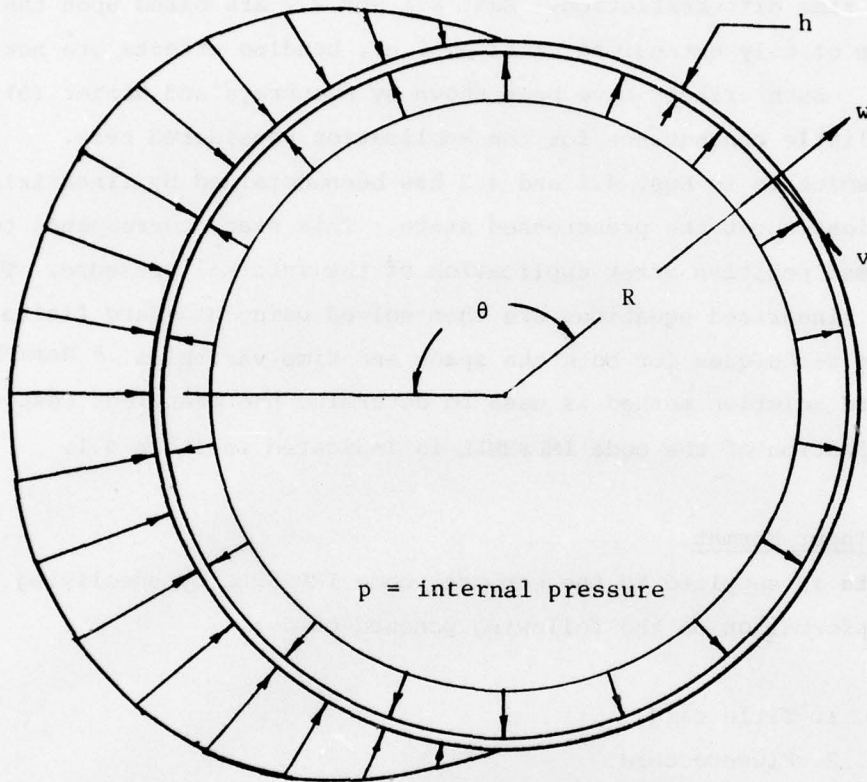


Figure 4.1. Coordinate System for Cylindrical Shell

In Eqs. 4.1 and 4.2, p , q , v , w , R , h , and θ are defined in Figure 4.2. N is the force per unit length in the circumferential direction, and ρ is the density. Subscripts preceded by a comma denote differentiation with respect to a spatial coordinate and dots over a variable are used to designate time differentiation. Eqs. 4.1 and 4.2 are based upon the assumption of only extensional motion, i.e., bending effects are not included. Such effects have been shown by Humphreys and Winter (9) to be of little consequence for the application considered here.

A solution to Eqs. 4.1 and 4.2 has been obtained by linearizing the equations about the prestressed state. This state corresponds to the deformed position after application of the internal pressure. The resulting linearized equations are then solved using standard finite difference techniques for both the space and time variables. A Nemark-Beta stepforward solution method is used to determine the transient response. The organization of the code IMPSHELL is indicated in Table 4.1.

4.3 Data Input Format

Data is supplied to the computer code IMPSHELL by specifying certain information on the following punched cards:

1. Title card
2. Fluence card
3. Spectrum definition cards
4. Material identification card
5. Photoelectric cross-section cards
6. Shell geometry and internal pressure card
7. Structural property card
8. Time and print sequence card

If several problems are to be run sequentially, cards 1 through 8 should be prepared for each problem and stacked sequentially. Normal termination of a run stream is accomplished by placing an END card at the end of the stacked data deck. Details of data card preparation for cards 1 through 8 are contained in Table 4.2.

Table 4.1 ORGANIZATIONAL CHART FOR IMPSHELL

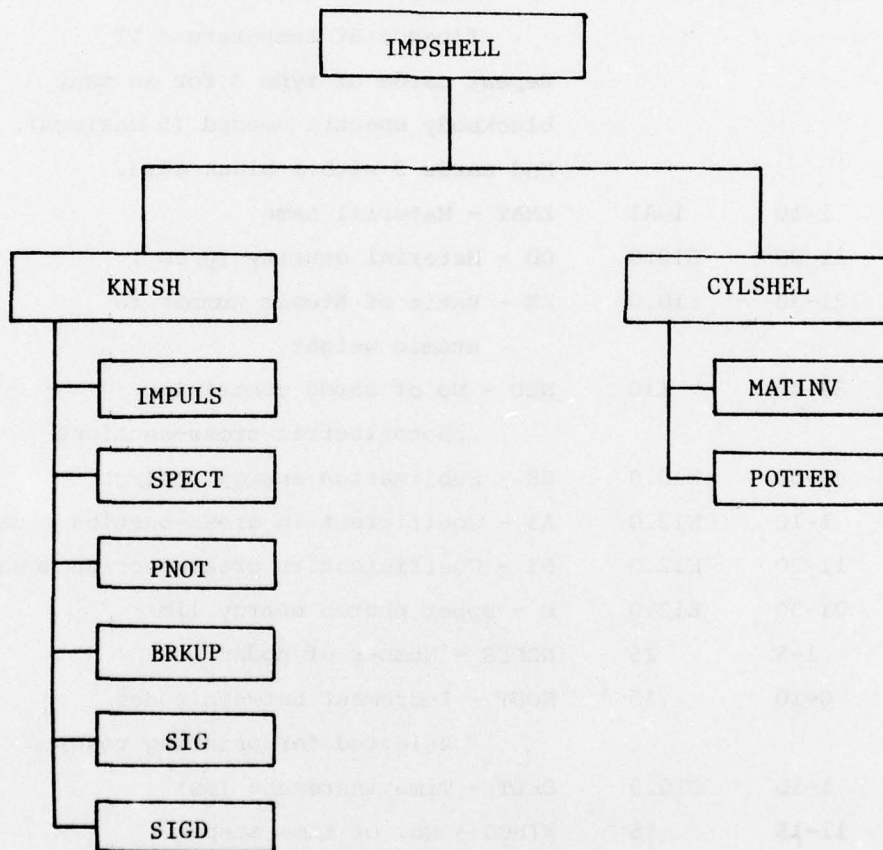


TABLE 4.2 DATA CARD DESCRIPTION FOR IMPSHELL

Card	Columns	Format	Data Item
1	1-80	80A1	TITLE - Any alphanumeric characters chosen to describe problem
2	1-10	E10.0	FLOONZ - Fluence (cal/cm ²)
	11-12	E10.0	SHINET - "Shine time" (μs)
3	1-10	E10.0	TT - Blackbody temperature (kev)
	11-12	E10.0	FF - Decimal fraction of total fluence at temperature TT
			Repeat cards of type 3 for as many blackbody spectra needed (5 maximum). End cards 3 with a blank card.
4	1-10	10A1	ZMAT - Material name
	11-20	E10.0	DD - Material density (g/cm ³)
	21-30	E10.0	ZZ - Ratio of Atomic number to atomic weight
	31-40	I10	NED - No of cards containing photoelectric cross-sections
5	41-50	E10.0	ES - Sublimation energy (cal/g)
	1-10	E12.0	A1 - Coefficient in cross-section equation
	11-20	E12.0	B1 - Coefficient in cross-section equation
6	21-30	E12.0	U - Upper photon energy limit
	1-5	I5	NODES - Number of nodes
7	6-10	I5	NOUT - Increment between nodes selected for printing results
	1-10	F10.0	DELT - Time increment (ms)
	11-15	I5	NINCS - No. of time steps
8	16-20	I5	DELP - Time steps between each print command.
	1-10	F10.0	PINT - Internal pressure (KN/m ²)

Card	Columns	Format	Data Item
9	1-15	F15.0	R - Shell radius (cm)
	16-30	F15.0	H - Shell thickness (cm)
	31-45	F15.0	E - Young's modulus (GN/m ²)
	46-60	F15.0	ANU - Poisson's ratio
	61-75	F15.0	RHO - Density (g/cm ³)

4.4 Sample Problem

To illustrate the data preparation steps, consider the problem of a cylindrical aluminum shell, 40 cm in radius, 0.6 cm thick, and pressurized internally by a pressure of 6895 KN/m^2 subjected to the energy flux from a 5 kev nuclear weapon detonation such that the fluence is 75 cal/cm^2 . The weapon "shine time" is 300 microseconds. Young's modulus for the aluminum is 68.95 GN/m^2 , Poisson's ratio is 0.3, and the density is 2.71 g/cm^3 . The data cards required to execute IMP SHELL for this problem are listed in Table 4.3.

As mentioned previously, IMP SHELL computes the displacements, stresses, and strains in the cylindrical shell as a function of time. The values at each node around the shell are printed at the frequency specified by the value of DELP. The results of the sample problem described above are presented in Table 4.4.

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PROGRAM IMPSHELL
 DEVELOPED BY THOMAS L. COST, ATHENA ENGINEERING COMPANY 88888

PROBLEM TITLE IMPSHELL SAMPLE PROBLEM. 7079 AL CYLINDER. 75 CAL/CM2. 5 KEV BB

THE FLUENCE FOR THIS PROBLEM IS 75000+02 CAL/CM2

THE UPPER BOUNDARIES ON THE HISTOGRAM ARE

5000+00	10000+01	15000+01	20000+01	25000+01	35833+01	46667+01	57500+01
6333+01	7667+01	9000+01	10333+02	11667+02	13333+02	14417+02	15500+02
16667+02	18000+02	19333+02	20667+02	22000+02	23333+02	24667+02	26000+02
27333+02	28667+02	30000+02	31333+02	32667+02	34000+02	35333+02	36667+02
38000+02	39333+02	40667+02	42000+02	43333+02	44667+02	46000+02	47333+02
50000+02	51333+02	52667+02	54000+02	55333+02	56667+02	58000+02	59333+02

BLACK BODY SPECTRUM TEMPERATURES AND RELATIVE WEIGHTS ARE

5000+01	10000+01
---------	----------

THIS PROBLEM CONSISTS OF 1 ZONES AS FOLLOWS

ZONE NO MATERIAL AL 7079 FAR DEPTH 1000+00 THICKNESS 1000+00 DENSITY 2700+01 Z/A 4814+00 NO EDGES 30

DOSE DEPTH	DOSE	PRIMARY COMPONENT	SCATTERED COMPONENT
10000+04	31899+04	31852+04	48577+01
20000+04	30906+04	30858+04	46750+01
30000+04	30231+04	30184+04	45908+01
40000+04	29638+04	29591+04	47064+01
50000+04	29034+04	28937+04	47188+01
60000+04	28521+04	28513+04	47315+01
70000+04	28085+04	28018+04	47434+01
80000+04	27595+04	27548+04	47548+01
90000+04	27149+04	27101+04	47653+01
100000+03	26725+04	26678+04	47756+01
120000+03	25939+04	25891+04	47848+01
140000+03	25225+04	25176+04	48127+01
160000+03	24574+04	24525+04	48295+01
180000+03	23978+04	23930+04	48454+01
200000+03	23431+04	23383+04	48605+01
220000+03	22927+04	22878+04	48750+01
240000+03	22461+04	22412+04	48888+01
260000+03	22029+04	21980+04	49022+01
280000+03	21626+04	21577+04	49158+01
300000+03	21250+04	21201+04	49275+01

Table 4.4 OUTPUT FROM IMPSHELL SAMPLE PROBLEM

51	32000-03	20858+04	20848+04	49395+01
58	34000-03	20557+04	20517+04	49512+01
59	36000-03	20458+04	20295+04	49625+01
60	38000-03	19861+04	19811+04	49735+01
61	40000-03	19682+04	19633+04	49843+01
62	50000-03	18482+04	18431+04	50342+01
63	60000-03	17517+04	17467+04	50789+01
64	70000-03	16716+04	16655+04	51193+01
65	80000-03	16033+04	15981+04	51582+01
66	90000-03	15439+04	15387+04	51959+01
67	10000-02	14910+04	14853+04	52210+01
68	20000-02	11849+04	11805+04	54304+01
69	30000-02	90619+03	90607+03	55268+01
70	40000-02	66370+03	66316+03	55495+01
71	50000-02	77139+03	76575+03	55558+01
72	60000-02	69789+03	69217+03	55287+01
73	70000-02	63859+03	63151+03	54817+01
74	80000-02	58670+03	58028+03	54262+01
75	90000-02	54161+03	53825+03	53841+01
76	10000-01	50321+03	49791+03	52977+01
77	20000-01	28354+03	27893+03	46156+01
78	30000-01	18954+03	18548+03	40516+01
79	40000-01	13929+03	13570+03	35942+01
80	50000-01	10049+03	9652+03	28951+01
81	60000-01	8729+02	8467+02	25833+01
82	70000-01	7878+02	7624+02	25354+01
83	80000-01	6195+02	5985+02	22200+01
84	90000-01	5206+02	5075+02	18914+01
85	10000+00	4558+02	4405+02	15141+01

IMPULSE DESCRIPTION

SUBLIMATION LAYER THICKNESS (CM) : 00000000
 IMPULSE (TAPS) : 4 00753045
 IMPULSE (N-MICROSECONDS/M2) : 400753 04356875
 MAXIMUM PRESSURE (N/M2) : 2671 68696088

888 DYNAMIC RESPONSE OF A CIRCULAR CYLINDER 888

PROBLEM TITLE > IMP-SHELL SAMPLE PROBLEM. 7079 AL CYLINDER. 75 CAL/CM2. 5 KEV BB

NUMBER OF NODES	62
NUMBER OF TIME INCREMENTS	4
BLAST LOADING TIME	00030000
TIME STEP	00010000
INTERNAL PRESSURE	6 89490708
CYLINDER RADIUS	40000000
BLAST LOAD MAGNITUDE	2671 68696088
NODAL POINT OUTPUT FREQUENCY	30
SHELL THICKNESS	00600000
MODULUS OF ELASTICITY	68949595616
POISSON'S RATIO	30000000
MATERIAL DENSITY	00000271
SOLUTION OUTPUT FREQUENCY	1
I/O TYPE - REAL(I) OR NORM(I)	0

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Table 4.4 (continued)

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TIME	THETA	U-DISP	U-DISP	U-DISP	U-VEL	U-VEL	U-VEL	STRESS	STRAIN
INCREMENT * 1									
1	00	- 15300974-04	- 88877889-03	- 11010003-18	- 48292027-15	- 10201204+06	- 14940330-06		
2	00	- 48141916-03	- 18210000-03	- 30148377-16	- 13748075-15	- 10855827+06	- 14874506-06		
3	00	- 14120000-07	- 19813189-04	- 10107344-19	- 14029006-16	- 10823364+06	- 14827843-06		
INCREMENT * 2									
1	00	- 30400236-05	- 14711974-03	- 24784730-16	- 95243303-15	- 26769848+05	- 37374834-06		
2	00	- 10630763-03	- 47995568-04	- 67823722-15	- 30917416-15	- 25621512+06	- 37159953-06		
3	00	- 30310002-08	- 49016737-05	- 22740084-19	- 31566117-16	- 25552994+05	- 37660179-06		
INCREMENT * 3									
1	00	- 76984354-05	- 29433076-03	- 3304256-16	- 12726956-14	- 51647814+05	- 74760861-06		
2	00	- 21073116-03	- 96003369-04	- 90430921-15	- 41218087-15	- 51863698+06	- 74340000-06		
3	00	- 76685553-08	- 98098760-06	- 30323699-19	- 42089727-16	- 51144711+05	- 74178521-06		
INCREMENT * 4									
1	00	- 76981215-05	- 29431875-03	- 44057871-16	- 16959992-14	- 5145060+05	- 74768463-06		
2	00	- 21072208-03	- 95999004-04	- 12057872-14	- 54952651-15	- 5140640+05	- 74383702-06		
3	00	- 76684336-08	- 98094506-05	- 40436379-19	- 56124011-16	- 51143008+05	- 74174187-06		

END DATA

Table 4.4 (continued)

5. CORRELATION OF EXPLODING FOIL IMPULSE TESTING
WITH NUCLEAR EFFECTS LOADS

The impulsive loads produced by sublimation effects of nuclear weapons is often simulated in the laboratory by the use of "exploding foil" techniques (10). In such test programs, thin films of metallic foils are bonded to the structural surface which experiences the impulsive loads. Large doses of electrical energy are discharged into the conducting foils from capacitor banks resulting in sublimation of the foil material. This sublimation, in turn, loads the structure impulsively. It is desirable to be able to correlate the simulation loads produced by the exploding foil techniques with the actual loads produced by nuclear weapon effects.

One procedure for correlating the results of the two phenomena is based on the equivalence of deposited energy and total impulse. It is assumed that the source of energy is unimportant and only the amount of energy deposited in the sublimated layer affects the impulse. Action times of the two effects are assumed to be approximately the same.

The procedure for calculating the impulsive loads due to nuclear weapon effects has been described in detail in Section 2.1. This procedure involves first determining the energy deposition profile in the material due to exposure to radiant energy from a nuclear weapon. This profile is calculated using an energy deposition code such as KNISH. After the profile is known, the total impulse is calculated using the Whitener model described in Section 2.1. A calculation which yields the total impulse per unit area (taps/cm^2) produced by the nuclear weapon effects.

To calculate the impulse produced by an exploding foil, use is made of the single-zone approximate method for impulse calculation defined as

$$I_B = 9150 \rho h \sqrt{E_d - E_s} \quad (5.1)$$

where

I_B = impulse per unit area of foil (taps/cm²)
 ρ = material density (g/cm³)
 h = foil thickness (cm)
 E_d = energy density in foil from capacitor discharge (cal/g)
 E_s = sublimation energy of material (cal/g)

To use Eq. 5.1 to calculate the impulse produced by an exploding foil, assume the known total amount of energy discharged by the capacitor bank, minus any losses, is deposited uniformly throughout the foil. This allows an energy density E_d to be calculated by dividing the net deposited energy by the number of grams of foil used. Substitution of E_d into Eq. 5.1, along with the thickness h and the material properties ρ and E_s , allows the impulse per unit area to be calculated.

Conversely, if the impulse produced by a given nuclear effects loading is known, the energy density required by the exploding foil technique to produce a similar impulse can be determined by solving Eq. 5.1 for E_d , i.e.,

$$E_d = E_s + \left[\frac{I_B}{9150\rho h} \right]^2 \quad (5.2)$$

Eq. 5.2 has been evaluated for the particular case of aluminum ($E_s = 3200$ cal/gm, $\rho = 2.71$ gm/cm³) for different thicknesses and the results presented graphically in Figure 5.1. This illustration permits a rapid determination to be made of the energy density requirements to simulate the results for a particular nuclear effects produced impulsive load.

As an example of how to use this information, assume that it is desired to simulate a nuclear explosive which produced an impulsive load of 1000 taps/cm². The foil material to be sublimated is aluminum with $\rho = 2.71$ g/cm³ and $E_s = 3200$ cal/g and is 0.0508 mm thick. Evaluating Eq. 5.2 gives a value for E_d of 3263 cal/g required to sublimate

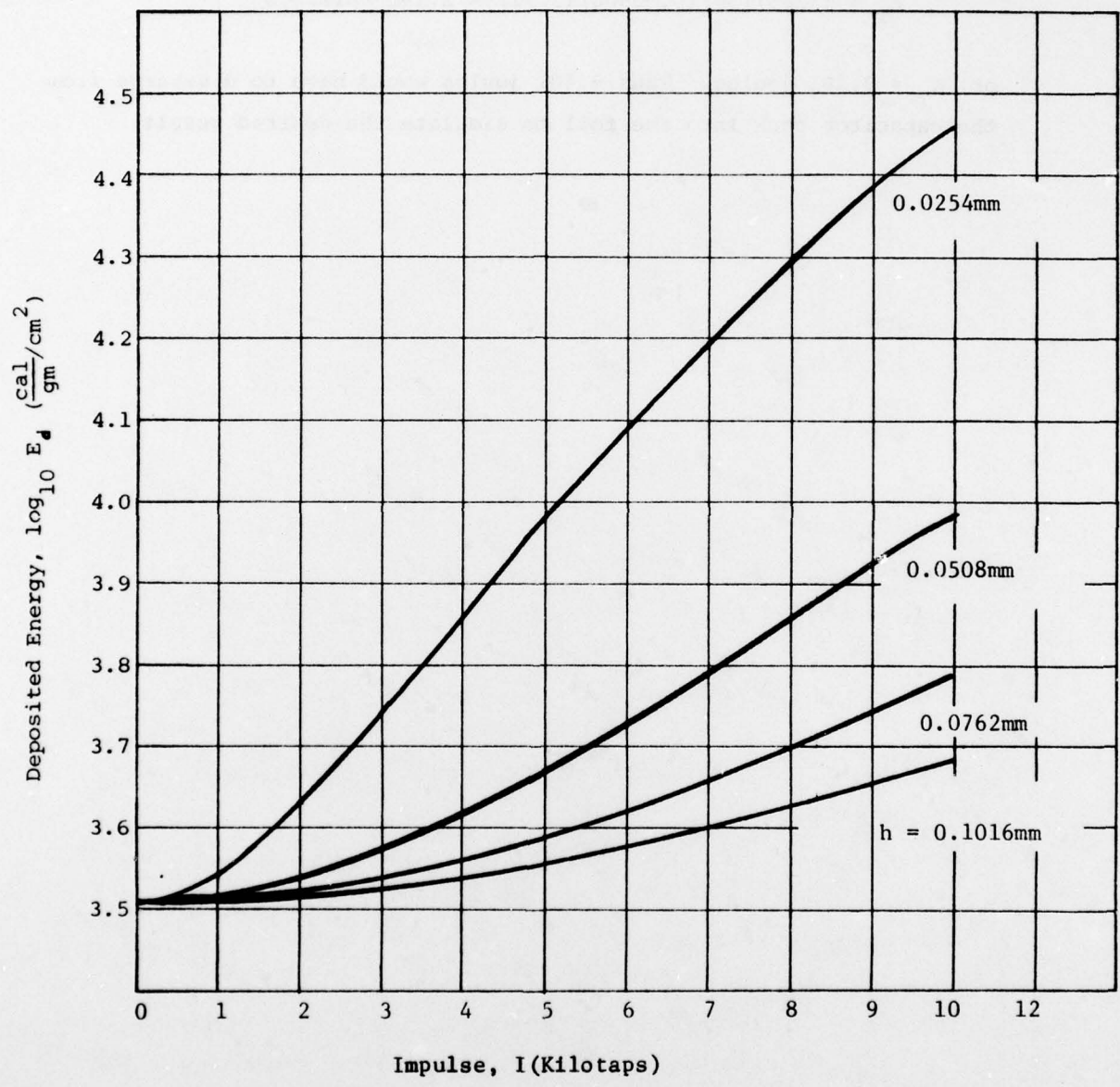
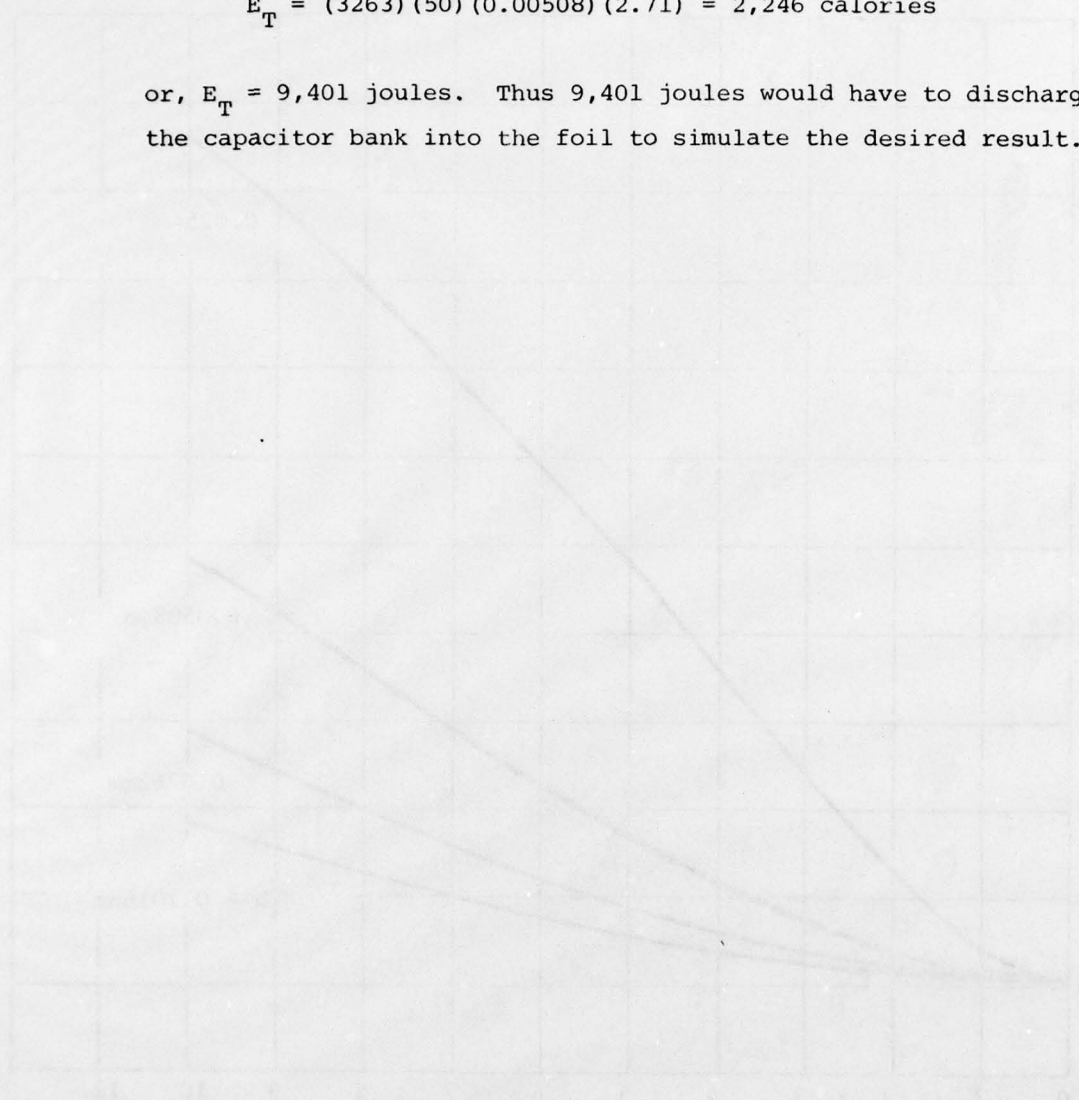


Figure 5.1. Correlation of Impulse and Deposited Energy

the foil at the desired impulse level. If the structural surface area to be loaded impulsively is 50 cm^2 , the total energy requirement is

$$E_T = (3263) (50) (0.00508) (2.71) = 2,246 \text{ calories}$$

or, $E_T = 9,401 \text{ joules}$. Thus 9,401 joules would have to discharge from the capacitor bank into the foil to simulate the desired result.



6. CLOSING REMARKS

The computer codes described in this report were designed to meet a particular need of the project sponsor. No attempt was made to create general purpose computer codes capable of assessing the spectrum of problems associated with the response of structures to electromagnetic radiation from a nuclear weapon. The codes serve the purpose for which they were intended: correlating specific experimental measurements with specific mathematical models. However, due to limitations placed on the models, the codes are not presently capable of assessing the vulnerability or survivability of missile structures. Still further code developments are needed to address these problems. The codes should be extended to include the following characteristics to make them more accurate:

1. material property dependence on temperature

At the high temperatures in question the material stiffness is decreased significantly which, in turn, significantly affects the structural response.

2. large deformation effects

The loads produced by nuclear weapon effects are sufficiently severe that large deformations are experienced before the structure fails.

3. failure criteria

Missile structures can withstand some permanent damage before failure occurs. The specific details of structural failure is important.

4. elastic-plastic material behavior

Material yielding and plastic deformations occur before the structure fails.

5. combined blast, impulsive, and operational loads

The operational loads produced by acceleration and pressurization are high as well as the blast and impulsive loads produced by nuclear weapon effects. The combined effects of all loads produces failure.

6. arbitrary geometrical shapes

More complex geometries than plates and cylinders must be evaluated.

7. composite material response

The response of layered, reinforced, composite materials to nuclear effects loads is important.

Each of these items is important in evaluating missile structural integrity and should be included in survivability/vulnerability studies.

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