

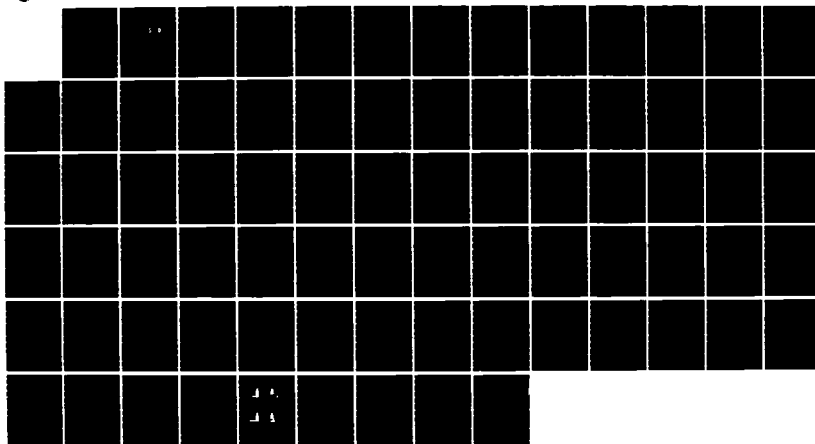
AD-A173 975

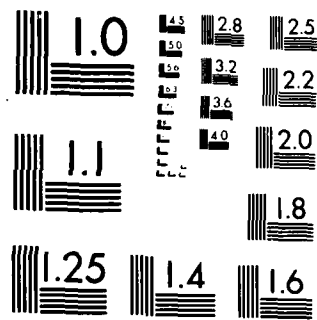
USER INSTRUCTIONS FOR THE EPIC-2 CODE(U) HONEYWELL INC 1/1
EDINA MN DEFENSE SYSTEMS DIV G R JOHNSON ET AL. SEP 86
AFATL-TR-86-51 F08635-83-C-0506

UNCLASSIFIED

F/G 9/2

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AFATL-TR-86-51

User Instructions for the EPIC-2 Code

G. R. Johnson
R. A. Stryk

HONEYWELL, INCORPORATED
DEFENSE SYSTEMS DIVISION
5901 SOUTH COUNTY ROAD 18
EDINA, MINNESOTA 55436

DTIC
ELECTE
OCT 28 1986
S D

SEPTEMBER 1986

FINAL REPORT FOR PERIOD OCTOBER 1983 - MAY 1986

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

DTIC FILE COPY

AIR FORCE ARMAMENT LABORATORY

Air Force Systems Command ■ United States Air Force ■ Eglin Air Force Base, Florida

86 10 27 037

AD-A173 975

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER



MARTIN F. ZIMMER
Chief, Munitions Division

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization, please notify AFATL/MNW, Eglin AFB FL 32542-5434.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A173975

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY NA			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution Unlimited		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE NA					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) 7-86-6			5. MONITORING ORGANIZATION REPORT NUMBER(S) AFATL-TR-86-51		
6a. NAME OF PERFORMING ORGANIZATION Honeywell Inc.		6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (City, State and ZIP Code) Defense Systems Division 5901 South County Road 18 Edina, Minnesota 55436			7b. ADDRESS (City, State and ZIP Code)		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Munitions Division		8b. OFFICE SYMBOL (If applicable) MNW	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F08635-83-C-0506		
8c. ADDRESS (City, State and ZIP Code) Air Force Armament Laboratory Eglin AFB, Florida 32542			10. SOURCE OF FUNDING NOS.		
11. TITLE (Include Security Classification) Users Instructions for the EPIC-2 Code			PROGRAM ELEMENT NO 2502	PROJECT NO 07	TASK NO 04
12. PERSONAL AUTHOR(S) G.R. Johnson and R.A. Stryk			15. PAGE COUNT 69		
13a. TYPE OF REPORT Final		13b. TIME COVERED FROM Oct 1983 to May 1986	14. DATE OF REPORT (Yr., Mo., Day) 1986 September		
16. SUPPLEMENTARY NOTATION Availability of this report is specified on verso of front cover.					
17. CCSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB GR.	NABOR Node Geometry Finite Difference Code		
			Quad Elements Triangular Elements		
			Eroding Slide Lines Variable Nodal Connectivity		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report provides user instructions for the 1986 version of the EPIC-2 code. The new capabilities in this code are a NABOR option for variable nodal connectivity, crushable materials, one dimensional geometry, plane stress geometry, quad elements, eroding interfaces, expanded postprocessing and a target add option. Instructions are included for the Preprocessor, the Main Routine and the Postprocessor. An example problem is also provided.					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED UNLIMITED ☐ SAME AS PPT ☒ DTIC USERS ☐			21. ABSTRACT SECURITY CLASSIFICATION		
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. Dennis L. May			22b. TELEPHONE NUMBER (Include Area Code) (904) 882-2141	22c. OFFICE SYMBOL AFATL/TRM	

PREFACE

This report on the EPIC-2 computer code was prepared by Honeywell Inc., Defense Systems Division, 5901 South County Road 18, Edina, Minnesota 55436, for the U.S. Air Force Armament Laboratory, Eglin Air Force Base, Florida 32542, under Contract F08635-83-C-0506.

This effort was conducted during the period from October 1983 to May 1986. The authors would like to thank Lts. Paul L. Thee, and Dennis L. May, AFATL/MNW program managers, and William H. Cook, AFATL/MNW, for many helpful technical discussions. Jack G. Dodd, professor at Colgate University and consultant to Honeywell, also contributed to this work.

Accession For	
NTIS CRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	



TABLE OF CONTENTS

Section	Title	Page
I	INTRODUCTION	1
II	USER INSTRUCTIONS	2
	Input Data for the Preprocessor	20
	Node Geometry	34
	Element Geometry	41
	Input Data for the Main Routine	45
	Input Data for the Postprocessor	52
	State Plots	52
	Time Plots	57
	Program Structure and File Designation	58
	Instructions for Changing Program Dimensions	64
	Central Processor Time Estimates	64
	Example Problem	64
III	CONCLUSIONS AND RECOMMENDATIONS	68
	REFERENCES	69

LIST OF ILLUSTRATIONS

Figure	Title	Page
1	Preprocessor Input Data	3
2	Material Input Data	5
3	Node Input Data	6
4	Element Input Data	7
5	Main Routine Input Data	8
6	Postprocessor Input Data for State Plots	9
7	Postprocessor Input Data for Time Plots	11
8	Nodal Spacing for Various Expansion Factors	12
9	Composite Element Geometry	13
10	Rod Shape Geometry	14
11	Nose Shape Geometry	15
12	Flat Plate Geometry	16
13	Sphere Geometry	17
14	NABOR Node Geometry	18
15	Pressure Model for Crushable Solids. Specific Data Shown are for Concrete	19
16	Hierarchy Chart for the Preprocessor and Main Routine	59
17	Hierarchy Chart for the State Plots Postprocessor	60
18	Hierarchy Chart for the Time Plots Postprocessor	61
19	Input Data for the Example Problem	65
20	Computed Response of Example Problem	66
21	Output Data for the Example Problem	67

LIST OF TABLES

Table	Title	Page
1	Subroutine Groupings for the EPIC-2 Code	62
2	Required Groups of Subroutines for Various Types of Runs	63

SECTION I INTRODUCTION

This report provides user instructions for the 1986 version of the EPIC-2 code.

The first documented version of the EPIC-2 code was developed for the Ballistic Research Laboratory (BRL) in 1977 (Reference 1). The second documented version was developed for the Air Force Armament Laboratory (AFATL) in 1983 (Reference 2). The 1983 version added expanded preprocessing and postprocessing capabilities, a heat conduction option, improved material models, a material data library, improved sliding interface capabilities, and a more accurate mass-lumping formulation.

The 1986 version, described in this report, incorporates a NABOR option for variable nodal connectivity. The essential nature of this option is that each node is affected only by its nearest neighbor nodes. As the nodes move closer than their equilibrium distance, they generate compressive, repulsive forces. Conversely, when they move apart, they generate tensile, attractive forces. Material strength effects are also included. The key to this approach is that it is possible to have variable connectivity; i.e., a node can take on new nearest neighbors, thus allowing all forms of distortion. Based on the concept of nearest neighbors, this option has been designated the NABOR option. A complete description of this approach will be presented in a forthcoming final report for this contract.

Other new features of the 1986 version are capabilities to include crushable materials (such as concrete), one dimensional geometry, plane stress geometry, two-dimensional quad elements (in addition to the standard triangular elements), eroding interfaces for projectile penetration into thick targets, expanded postprocessing, and a target add option.

Although quad elements are being introduced as an option, one of the distinguishing features of the EPIC-2 code is that it is primarily based on a triangular element formulation. This allows problems with severe distortions to be run without rezoning. This is a very desirable feature for many intense impulsive loading problems involving high velocity impact or explosive detonation.

SECTION II USER INSTRUCTIONS

This section provides user instructions for the EPIC-2 code. The code consists of a Preprocessor, Main Routine and Postprocessor for state and time plots. The formulation is not provided here; however, most of the equations are identical to those of the original version, (Reference 1). Some comments concerning the formulation of the current version of the code follow:

- The crossed triangle arrangement of triangular elements (four triangles in a quadrilateral) has been shown to give better accuracy and should be used in most instances (Reference 3).
- The sliding interface formulation is similar to that used in the three-dimensional EPIC-3 code (References 4 and 5).
- The eroding interface option is described in Reference 6.
- The heat conduction option is described in Reference 7.
- The plane stress option is described in Reference 8.
- The NABOR and quad element formulations will appear in the final report for this contract. The NABOR formulation for plane strain is given in Reference 9.
- A characteristic of triangular elements is that they sometimes produce a pressure field that oscillates spatially. This can cause inaccuracies for cases where the material strength or fracture is dependent on the pressure in the element. This is overcome by computing a nodal pressure which is the average of the element pressures for all elements which contain a specified node. The nodal pressures do not oscillate spatially but rather form a smooth pressure field. A smoothed element pressure is then defined as the average of the three associated nodal pressures. This smoothed pressure is used for the strength and fracture models which are pressure dependent (Reference 3).

A description of input data for the EPIC-2 code is given in Figures 1 through 15.

DESCRIPTION CARD (215, A60)

CASE	TYPE	DESCRIPTION OF PROBLEM	
------	------	------------------------	--

MISCELLANEOUS CARD (1615)

GEOM	PRINT	SAVE	NMAS	NRIG	NCHNK	NSLID	IZR	SPLIT	NTOP	NBOT	NRING	AVEP	CDUCT	UNIT	NRST
------	-------	------	------	------	-------	-------	-----	-------	------	------	-------	------	-------	------	------

MATERIAL DATA CARDS - DESCRIPTION FOLLOWS

BLANK CARD	ENDS MATERIAL DATA
------------	--------------------

PROJECTILE SCALE/SHIFT/ROTATE CARD (5F10.0)

RSCALE	ZSCALE	ROTATE	RSHIFT	ZSHIFT	
--------	--------	--------	--------	--------	--

NODE DATA CARDS FOR PROJECTILE - DESCRIPTION FOLLOWS

BLANK CARD	ENDS PROJECTILE NODE DATA
------------	---------------------------

TARGET SCALE/SHIFT/ROTATE CARD (5F10.0)

RSCALE	ZSCALE	ROTATE	RSHIFT	ZSHIFT	
--------	--------	--------	--------	--------	--

NODE DATA CARDS FOR TARGET - DESCRIPTION FOLLOWS

BLANK CARD	ENDS TARGET NODE DATA
------------	-----------------------

ELEMENT DATA CARDS FOR PROJECTILE - DESCRIPTION FOLLOWS

BLANK CARD	ENDS PROJECTILE ELEMENT DATA
------------	------------------------------

ELEMENT DATA CARDS FOR TARGET - DESCRIPTION FOLLOWS

BLANK CARD	ENDS TARGET ELEMENT DATA
------------	--------------------------

CONCENTRATED MASS CARDS - AS REQUIRED (15, 5X, F10.0)

N	MASS(N)	
---	---------	--

RIGID BODY IDENTIFICATION CARDS - AS REQUIRED (215)

NRN	NRG	
-----	-----	--

INDIVIDUAL RIGID BODY NODES CARDS - FOR NRG = 0 (1615)

R1	R2								RN						
----	----	--	--	--	--	--	--	--	----	--	--	--	--	--	--

NRG GROUPED RIGID BODY NODES CARDS (315)

RIG	RNG	INT	
-----	-----	-----	--

* INDICATES REQUIRED CARDS ALL OTHERS OPTIONAL

Figure 1. Preprocessor Input Data

CHUNK DATA IDENTIFICATION CARDS - AS REQUIRED (215)

NCE	NEG														
-----	-----	--	--	--	--	--	--	--	--	--	--	--	--	--	--

INDIVIDUAL ELEMENT CHUNK CARDS - FOR NEG = 0 (1615)

E1	E2								EN						
----	----	--	--	--	--	--	--	--	----	--	--	--	--	--	--

NEG GROUPED ELEMENT CHUNK CARDS (315)

E1G	ENG	INC													
-----	-----	-----	--	--	--	--	--	--	--	--	--	--	--	--	--

SLIDE LINE IDENTIFICATION CARDS - AS REQUIRED (815, 3F10.0)

NSN	NSN	NSG	NSG	IT1	IT2	SEEK	MBOT	FRICTION	REF VEL	ERODE					
-----	-----	-----	-----	-----	-----	------	------	----------	---------	-------	--	--	--	--	--

INDIVIDUAL MASTER NODE CARDS - FOR NSG = 0 (1615)

M1	M2								MN						
----	----	--	--	--	--	--	--	--	----	--	--	--	--	--	--

NSG GROUPED MASTER NODE CARDS (315)

M1G	MNG	INC													
-----	-----	-----	--	--	--	--	--	--	--	--	--	--	--	--	--

INDIVIDUAL SLAVE NODE CARDS - FOR NSG = 0 AND NSN > 0 (1615)

S1	S2								SN						
----	----	--	--	--	--	--	--	--	----	--	--	--	--	--	--

NSG GROUPED SLAVE NODE CARDS - FOR NSG > 0 AND NSN > 0 (315)

S1G	SNG	INC													
-----	-----	-----	--	--	--	--	--	--	--	--	--	--	--	--	--

SLAVE NODE LIMITS CARD - FOR NSN=0 (4F10.0)

RMAX	RMIN	ZMAX	ZMIN												
------	------	------	------	--	--	--	--	--	--	--	--	--	--	--	--

RESTRAINED NODES IDENTIFICATION CARDS - AS REQUIRED (215, 2X, 311)

NFN	NFG														
-----	-----	--	--	--	--	--	--	--	--	--	--	--	--	--	--

INDIVIDUAL RESTRAINED NODES CARDS - FOR NFG=0 (1615)

F1	F2								FN						
----	----	--	--	--	--	--	--	--	----	--	--	--	--	--	--

NFG GROUPED RESTRAINED NODES CARDS (315)

F1G	FNG	INC													
-----	-----	-----	--	--	--	--	--	--	--	--	--	--	--	--	--

VELOCITY/DETONATION CARD (8F10.0)

PRDOT	PZDOT	PTDOT	TRDOT	TZDOT	TTDOT	RDET	ZDET	*
-------	-------	-------	-------	-------	-------	------	------	---

INITIAL INTEGRATION CARD (3F10.0)

DT1	TBURN	BETA													*
-----	-------	------	--	--	--	--	--	--	--	--	--	--	--	--	---

Figure 1. Preprocessor Input Data (Concluded)

MATERIAL CARDS FOR SOLIDS FROM LIBRARY (415, 2F5.0)

MATL	0	IDAM	IFAIL	DFRAC	EFAIL			
------	---	------	-------	-------	-------	--	--	--

5 MATERIAL CARDS FOR SOLIDS INPUT DATA [415, 5X, F5.0, A48, 4(8F10.0)]

MATL	1	IDAM	IFAIL	EFAIL	MATERIAL DESCRIPTION			
------	---	------	-------	-------	----------------------	--	--	--

DENSITY	SPH HEAT	CONDUCT	ALPHA	TEMP1	TROOM	TMELT	X1
---------	----------	---------	-------	-------	-------	-------	----

SHEAR MOD	C1	C2	N	C3	M	C4	SMAX
-----------	----	----	---	----	---	----	------

K1	K2	K3	L	CL	CQ	PMIN	CH
----	----	----	---	----	----	------	----

D1	D2	D3	D4	D5	SPALL	EFMIN	X2
----	----	----	----	----	-------	-------	----

MATERIAL CARDS FOR EXPLOSIVES FROM THE LIBRARY (215)

MATL	0							
------	---	--	--	--	--	--	--	--

3 MATERIAL CARDS FOR EXPLOSIVES INPUT DATA (215, 20X, A48/6F10.0/7F10.0)

MATL	2				MATERIAL DESCRIPTION			
------	---	--	--	--	----------------------	--	--	--

DENSITY	ENERGY	DET VEL	CL	CQ	CH			
---------	--------	---------	----	----	----	--	--	--

C1	C2	C3	C4	C5	X1	X2		
----	----	----	----	----	----	----	--	--

MATERIAL CARDS FOR CRUSHABLE SOLIDS FROM LIBRARY (215, 15X, F5.0)

MATL	0				EFAIL			
------	---	--	--	--	-------	--	--	--

4 MATERIAL CARDS FOR CRUSHABLE SOLIDS INPUT DATA [215, 15X, F5.0, A48/3F10.0/2(8F10.0)]

MATL	5				EFAIL	MATERIAL DESCRIPTION		
------	---	--	--	--	-------	----------------------	--	--

DENSITY	SPH HEAT	TEMP1						
---------	----------	-------	--	--	--	--	--	--

SHEAR MOD	C1	C4	SMAX	CL	CQ	PMIN	CH
-----------	----	----	------	----	----	------	----

PCRUSH	THRUSH	K1	K2	K3	KLOCK	ULOCK	X1
--------	--------	----	----	----	-------	-------	----

Figure 2. Material Input Data

LINE OF NODES DESCRIPTION CARD (415, 2X, 311, 5X, 5410.0)

1	N1	NN	INC				R1	Z1	RN	ZN	EXPAND
---	----	----	-----	--	--	--	----	----	----	----	--------

IR, IZ, IT

ROD NODE DESCRIPTION CARD (615, 3F10.0)

2	N1	NRING	NPLN	IRAD	ICROS	ZTOP	ZBOT	EXPAND	
---	----	-------	------	------	-------	------	------	--------	--

ROD NODE RADII CARD FOR IRAD = 0 OR 3 OR 4 (4F10.0)

ROTOP	RITOP	ROBOT	RIBOT	
-------	-------	-------	-------	--

ROD NODE TOP RADII CARD(S) FOR IRAD = 1 OR 2 (8F10.0)

RT(1)					RT(NRING)		
-------	--	--	--	--	-----------	--	--

ROD NODE BOTTOM RADII CARD(S) FOR IRAD = 1 OR 2 (8F10.0)

RB(1)					RB(NRING)		
-------	--	--	--	--	-----------	--	--

ROD NODE TOP SURFACE CARD(S) FOR IRAD = 1 OR 3 (8F10.0)

ZT(1)					ZT(NRING)		
-------	--	--	--	--	-----------	--	--

ROD NODE BOTTOM SURFACE CARD(S) FOR IRAD = 1 OR 3 (8F10.0)

ZB(1)					ZB(NRING)		
-------	--	--	--	--	-----------	--	--

ROD NODE TOP SURFACE CARD FOR IRAD = 2 OR 4 (8F10.0) $ZT(I) = A0 + A1 \cdot RT(I) + \dots + A6 \cdot RT(I)^6 + A7(1 - \cos \theta)$

A0	A1	A2	A3	A4	A5	A6	A7
----	----	----	----	----	----	----	----

ROD NODE BOTTOM SURFACE CARD FOR IRAD = 2 OR 4 (8F10.0) $ZB(I) = B0 + B1 \cdot RB(I) + \dots + B6 \cdot RB(I)^6 + B7(1 - \cos \theta)$

B0	B1	B2	B3	B4	B5	B6	B7
----	----	----	----	----	----	----	----

NOSE NODE DESCRIPTION CARD (615, 3F10.0)

3	N1	NRING	INOSE	IRAD	ICROS	RTOP	ZTOP	ZBOT	
---	----	-------	-------	------	-------	------	------	------	--

NOSE NODE TOP RADII CARD(S) FOR IRAD = 1 (8F10.0)

RT(1)					RT(NRING)		
-------	--	--	--	--	-----------	--	--

NOSE NODE ZMIN CARD(S) FOR IRAD = 1 (8F10.0)

ZB(1)					ZB(NRING)		
-------	--	--	--	--	-----------	--	--

FLAT PLATE DESCRIPTION CARD (615, 4F10.0)

4	N1	INC	IRFIX	IJOIN	ICROS	RMAX	RMIN	ZMAX	ZMIN	
---	----	-----	-------	-------	-------	------	------	------	------	--

FLAT PLATE EXPANSION CARD (415, 10X, 4F10.0)

NR	NZ	NREND	NZEND		RPART	R-EXPAND	ZPART	Z-EXPAND	
----	----	-------	-------	--	-------	----------	-------	----------	--

SPHERE NODE DESCRIPTION CARD (415, 10X, 2F10.0)

5	N1	NRING	ICROS		ZTOP	ZBOT	
---	----	-------	-------	--	------	------	--

LABOR NODE DESCRIPTION CARD (315, 15X, 5F10.0)

6	N1	MATL			RMAX	RMIN	ZMAX	ZMIN	NODE DIA
---	----	------	--	--	------	------	------	------	----------

Figure 3. Node Input Data

SERIES OF COMPOSITE ELEMENTS DESCRIPTION CARD (1015)

1	NCOMP	MATL	N1	N2	N3	N4	N5	INC	L1										
---	-------	------	----	----	----	----	----	-----	----	--	--	--	--	--	--	--	--	--	--

ROD ELEMENT DESCRIPTION CARD (715)

2	N1	MATL	NRCOL	NZLAY	IDTAG	L1										
---	----	------	-------	-------	-------	----	--	--	--	--	--	--	--	--	--	--

MATERIAL CARD FOR MATL = 0 (1615)

M(1)									M(NRCOL)						
------	--	--	--	--	--	--	--	--	----------	--	--	--	--	--	--

ROD ELEMENT DESCRIPTION CARD (415, 5X, 215)

3	N1	MATL	NRCOL		IDTAG	L1										
---	----	------	-------	--	-------	----	--	--	--	--	--	--	--	--	--	--

MATERIAL CARD FOR MATL = 0 (1615)

M(1)									M(NRCOL)						
------	--	--	--	--	--	--	--	--	----------	--	--	--	--	--	--

FLAT PLATE ELEMENT DESCRIPTION CARD (715)

4	N1	MATL	NRCOL	NZLAY	IDTAG	L1										
---	----	------	-------	-------	-------	----	--	--	--	--	--	--	--	--	--	--

SPHERE ELEMENT DESCRIPTION CARD (415, 5X, 215)

5	N1	MATL	NRCOL		IDTAG	L1										
---	----	------	-------	--	-------	----	--	--	--	--	--	--	--	--	--	--

MATERIAL CARD FOR MATL = 0 (1615)

M(1)									M(NRCOL)						
------	--	--	--	--	--	--	--	--	----------	--	--	--	--	--	--

Figure 4. Element Input Data

RESTART DESCRIPTION CARD - FOR RESTART ONLY (215, A60)

CASE	3	DESCRIPTION OF PROBLEM	
------	---	------------------------	--

TIME INTEGRATION CARD (215, 7F10.0)

CYCLE	CHANG	DTMAX	DTMIN	SSF	TMAX	LPMAX	EMAX	VNREF	*
-------	-------	-------	-------	-----	------	-------	------	-------	---

CHANGE DROP CARD FOR CHANG=1 OR 2 (F10.0, 1315)

TDROP	NODE	PNODE	ELE	PELE	NMAS	NRIG	NCHK	NSLID	NPLOT	LPIOT	NFAIL	NAB	PNAB	
-------	------	-------	-----	------	------	------	------	-------	-------	-------	-------	-----	------	--

DESIGNATED ELEMENT FAILURE CARD - FOR NFAIL > 0 (1615)

EF1	EF2							EFN						
-----	-----	--	--	--	--	--	--	-----	--	--	--	--	--	--

CHANGE ADD CARD FOR CHANG=2 OR 3 (F10.0, 1115)

TADD	NMAS	NRIG	NCHK	NSLID	IZR	SPLIT	NTOP	NBOT	NRING	NRSI	IPRNT	
------	------	------	------	-------	-----	-------	------	------	-------	------	-------	--

TARGET SCALE/SHIFT/ROTATE CARD FOR CHANG=2 OR 3 (5F10.0)

RSCALE	ZSCALE	ROTATE	RSHIFT	ZSHIFT	
--------	--------	--------	--------	--------	--

ADDITIONAL TARGET NODE DATA FOR CHANG=2 OR 3 - AS REQUIRED

BLANK CARD	ENDS NODE DATA FOR CHANG=2 OR 3
------------	---------------------------------

ADDITIONAL TARGET ELEMENT DATA FOR CHANG=2 OR 3 - AS REQUIRED

BLANK CARD	ENDS ELEMENT DATA FOR CHANG=2 OR 3
------------	------------------------------------

NMAS DATA - AS REQUIRED FOR CHANG=2 OR 3

NRIG DATA - AS REQUIRED FOR CHANG=2 OR 3

NCHK DATA - AS REQUIRED FOR CHANG=2 OR 3

NSLID DATA - AS REQUIRED FOR CHANG=2 OR 3

NRSI DATA - AS REQUIRED FOR CHANG=2 OR 3

} SAME FORMAT AS USED IN PREPROCESSOR

TARGET VELOCITY CARD FOR CHANG=2 OR 3 (30X, 3F10.0)

			TRDOT	TZDOT	TTDOT	
--	--	--	-------	-------	-------	--

BLANK CARD	ENDS DATA FOR CHANG=2 OR 3
------------	----------------------------

PLOT CARD (415, 4F10.0)

PCYCL	SYS	NPLOT	LPIOT	DT SYS	TSYS	DT NODE	TNODE		*
-------	-----	-------	-------	--------	------	---------	-------	--	---

DESIGNATED NODES CARD - FOR NPLOT > 0 (1615)

N1	N2							NN						
----	----	--	--	--	--	--	--	----	--	--	--	--	--	--

DESIGNATED ELEMENTS CARD - FOR LPIOT > 0 (1615)

E1	E2							EN						
----	----	--	--	--	--	--	--	----	--	--	--	--	--	--

DATA OUTPUT CARDS - AS REQUIRED (3F10.0, 615)

TIME	ECHK	RDAMP	SAVE	LOAD	CHUNK	BURN	NDA	PLOT		*
------	------	-------	------	------	-------	------	-----	------	--	---

BLANK CARD	ENDS MAIN ROUTINE DATA	*
------------	------------------------	---

Figure 5. Main Routine Input Data

[illegible]

RMAX	RMIN	ZMAX	ZMIN	
------	------	------	------	--

2	CYCLE	TIME						VSCALE	TITLE
---	-------	------	--	--	--	--	--	--------	-------

ARROW
 EDGE
 SIDE
 ORIENT
 AXES

RMAX	RMIN	ZMAX	ZMIN	
------	------	------	------	--

[illegible]

RMAX	RMIN	ZMAX	ZMIN	
------	------	------	------	--

C1	C2			CN			
----	----	--	--	----	--	--	--

TYPE	CYCLE	TIME			TITLE
			AXES	PRINT	
				TYPE	<u>VARIABLE VS Z AXIS</u>
				2	Z VELOCITY
				3-10	SAME AS CONTOURS

V _{MAX}	V _{MIN}	I _{MAX}	I _{MIN}	
------------------	------------------	------------------	------------------	--

9

JET CHARACTERISTICS PLOT CARD (215, F10.0, 212, 26X, A30)

TYPE	CYCLE	TIME					TITLE
------	-------	------	--	--	--	--	-------

AXES = 1, A(10M)

TYPE	VARIABLE PLOTTED
11	ACCUMULATED MASS VS Z AXIS
12	ACCUMULATED MASS VS Z VELOCITY
13	ACCUMULATED MOMENTUM VS Z AXIS
14	ACCUMULATED KINETIC ENERGY VS Z AXIS
15	Z VELOCITY VS Z AXIS
16	R VELOCITY VS INITIAL R COORDINATES*
17	Z VELOCITY VS INITIAL R COORDINATES*

FOR PROJECTILE NODES ONLY

* IF CYCLE 0 DATA ARE NOT ON THE RESTART FILE, THE CURRENT R COORDINATES WILL BE USED IN PLACE OF THE INITIAL R COORDINATES

PLOT LIMITS CARD FOR AXES = 2 AND TYPE = 11-15 (4F10.0)

VMAX	VMIN	Z/Z MAX	Z/Z MIN	
------	------	---------	---------	--

PLOT LIMITS CARD FOR AXES = 2 AND TYPE = 16-17 (4F10.0)

R/Z MAX	R/Z MIN	RMAX	RMIN	
---------	---------	------	------	--

BEHIND-TARGET DEBRIS PLOT CARD (212, F10.0, 412, 12X, F10.0, A30)

TYPE	CYCLE	TIME					ZPLATE	TITLE
------	-------	------	--	--	--	--	--------	-------

NPART	TYPE	VARIABLE PLOTTED
NBIN	18	MOMENTUM/AREA
VCUT	19	KINETIC ENERGY/AREA
OPTION	20	MASS/AREA
	21	NODE VELOCITY

PLOT LIMITS CARD (5F10.0)

VMAX	VMIN	HMAX	HMIN	V CUTOFF	
------	------	------	------	----------	--

EXTRAPOLATED GEOMETRY PLOT CARD (215, F10.0, 612, 8X, F10.0, A30)

22	CYCLE	TIME					1-EXTRAP	TITLE
----	-------	------	--	--	--	--	----------	-------

	NOIR
	PLAT
	EDGE
	LINE
	ORIENT
	AXES

PLOT LIMITS CARD FOR AXES=2 (4F10.0)

RMAX	RMIN	ZMAX	ZMIN	
------	------	------	------	--

BLANK PAGE	END OF INPUT DATA
------------	-------------------

Figure 6. Postprocessor Input Data for State Plots (Concluded)

SYSTEM PLOT CARDS - AS REQUIRED (215, 5X, F5.0, 4F10.0, A18)

TYPE	AXES	SCALE	TMAX	TMIN	VMAX	VMIN	TITLE
------	------	-------	------	------	------	------	-------

INDIVIDUAL NODE PLOT CARDS - AS REQUIRED (315, F5.0, 4F10.0, A18)

TYPE	AXES	NODE	SCALE	TMAX	TMIN	VMAX	VMIN	TITLE
------	------	------	-------	------	------	------	------	-------

INDIVIDUAL ELEMENT PLOT CARDS - AS REQUIRED (315, F5.0, 4F10.0, A18)

TYPE	AXES	ELE	SCALE	TMAX	TMIN	VMAX	VMIN	TITLE
------	------	-----	-------	------	------	------	------	-------

BLANK CARD ENDS TIME PLOTS DATA

TYPE	VARIABLE PLOTTED	
1- 4	ENERGIES: TOTAL (1), KINETIC (2), INTERNAL (3), PLASTIC WORK (4)	SYSTEM DATA
5- 6	R - Z MAXIMUM COORDINATES	
7- 8	R - Z MINIMUM COORDINATES	
9-10	R - Z CENTERS OF GRAVITY	
11-12	R - Z LINEAR MOMENTA	
13-14	R - Z LINEAR VELOCITIES	
15	NET VELOCITY (R-Z PLANE)	
16	ANGULAR MOMENTUM	NODE DATA
17	ANGULAR VELOCITY	
18-20	R - Z - θ NODE POSITIONS	
21-23	R - Z - θ NODE VELOCITIES	
24-26	R - Z - θ NODE ACCELERATIONS	
27	NET VELOCITY (R-Z PLANE)	
28	DIRECTION, $\theta = \text{ARCTAN}(\text{RDOT}/\text{ZDOT})$	
29	NODAL PRESSURE (FOR AVEP = 0 ONLY)	ELEMENT DATA
30	NODAL TEMPERATURE (FOR CDUCT = 1 ONLY)	
31	ELEMENT PRESSURE	
32	VON MISES STRESS	
33	RATIO: MEAN STRESS/VON MISES STRESS	
34	EQUIVALENT STRAIN	
35	LOG (10) STRAIN RATE	
36	TEMPERATURE	
37	DAMAGE	
38	INTERNAL ENERGY PER INITIAL VOLUME	
39	PLASTIC WORK PER INITIAL VOLUME	

Figure 7. Postprocessor Input Data for Time Plots

[illegible]

$$\Delta_{i+1} = \Delta_i \cdot \text{EXPAND}$$

$$\frac{\Delta_N}{\Delta} = \frac{N \left(1 - \frac{1}{\text{EXPAND}} \right)}{\left[1 - \left(\frac{1}{\text{EXPAND}} \right)^N \right]}$$

12

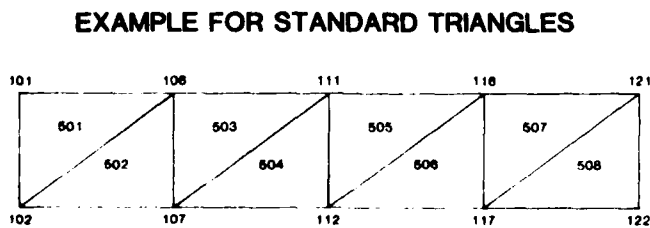
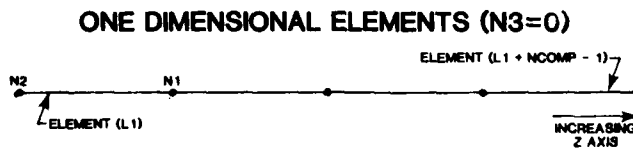
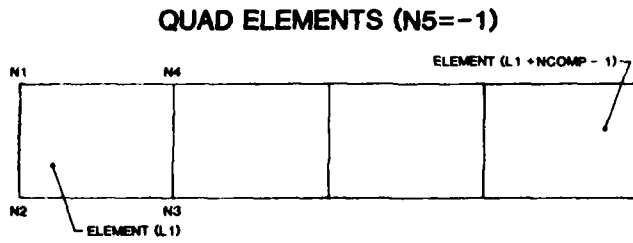
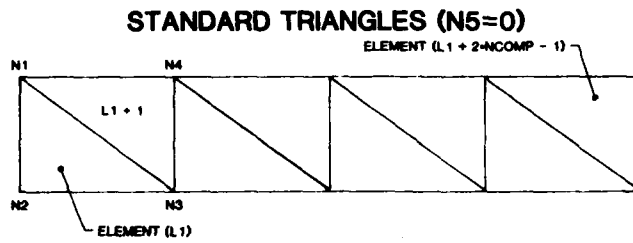
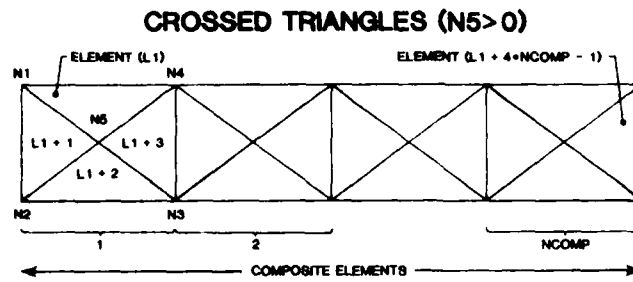


Figure 9. Composite Element Geometry

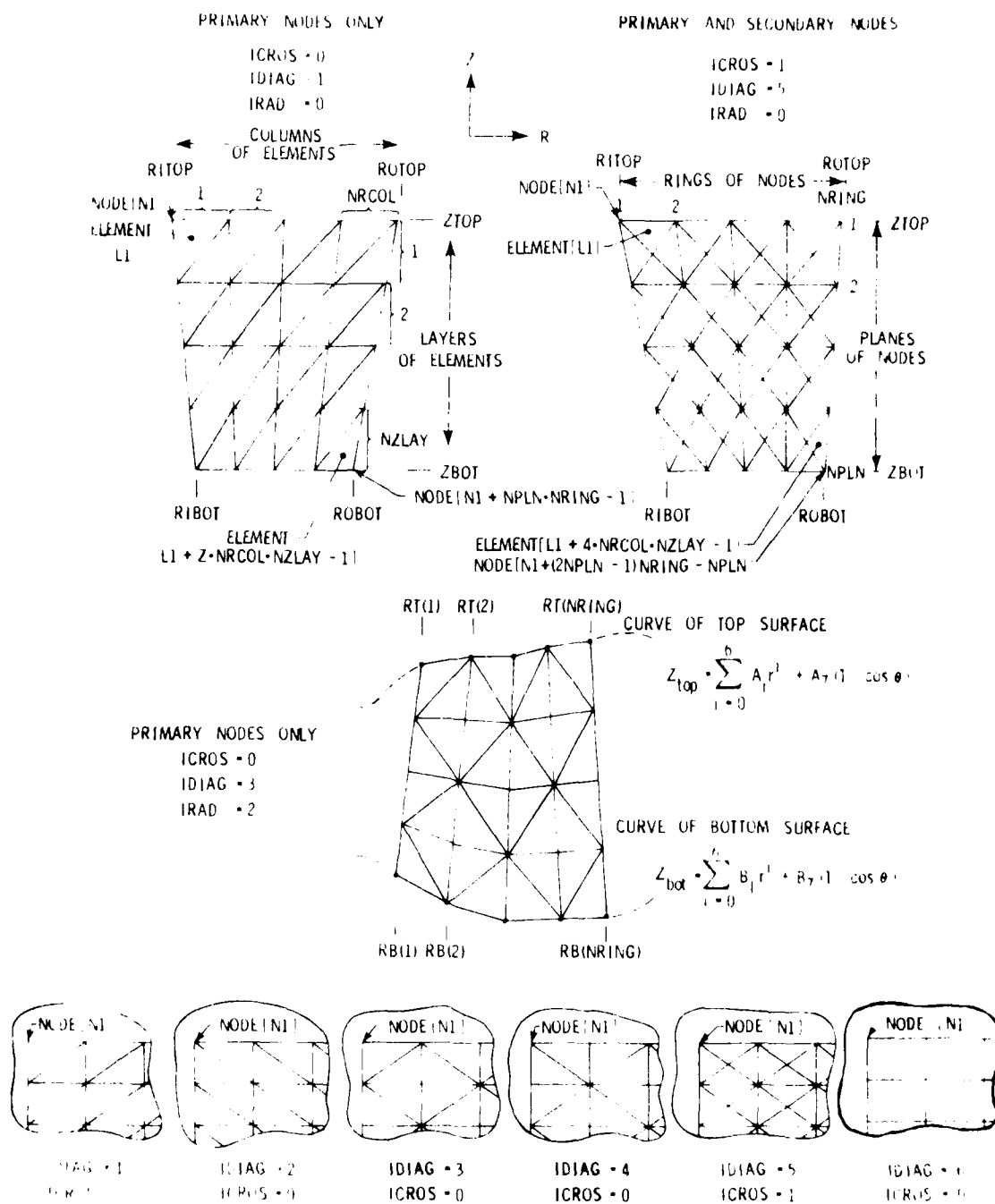
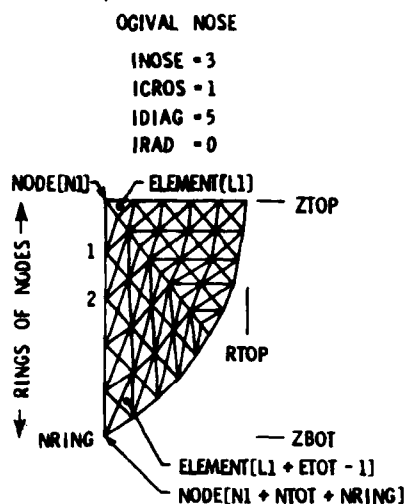
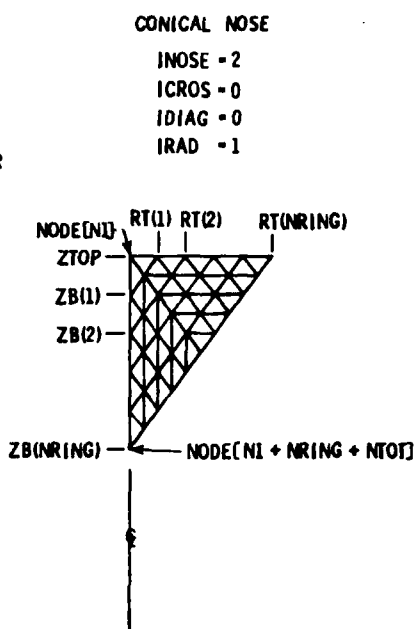
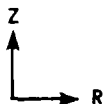
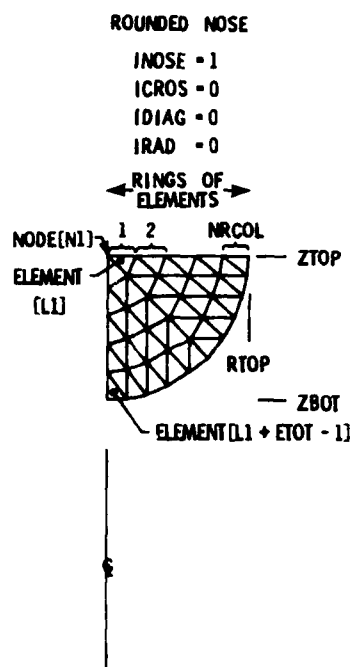


Figure 10. Rod Shape Geometry



NUMBER OF RINGS (NRING)	NUMBER OF NODES* (NTOT)		NUMBER OF ELEMENTS (ETOT)		
	ICROS = 0	ICROS = 1	IDIAG = 0	IDIAG = 5	IDIAG = 6
1	2	3	2	4	1
2	6	10	8	16	4
3	12	21	18	36	9
4	20	36	32	64	16
5	30	55	50	100	25
6	42	78	72	144	36
7	56	105	98	196	49
8	72	136	128	256	64
9	90	171	162	324	81
10	110	210	200	400	100
N	$N^2 + N$	$2N^2 + N$	$2N^2$	$4N^2$	N^2

*DOES NOT INCLUDE ROD - NOSE INTERFACE NODES

NOTES FOR QUAD ELEMENTS

- USE ICROS = 0 FOR NODES
- USE IDIAG = 6 FOR ELEMENTS

Figure 11. Nose Shape Geometry

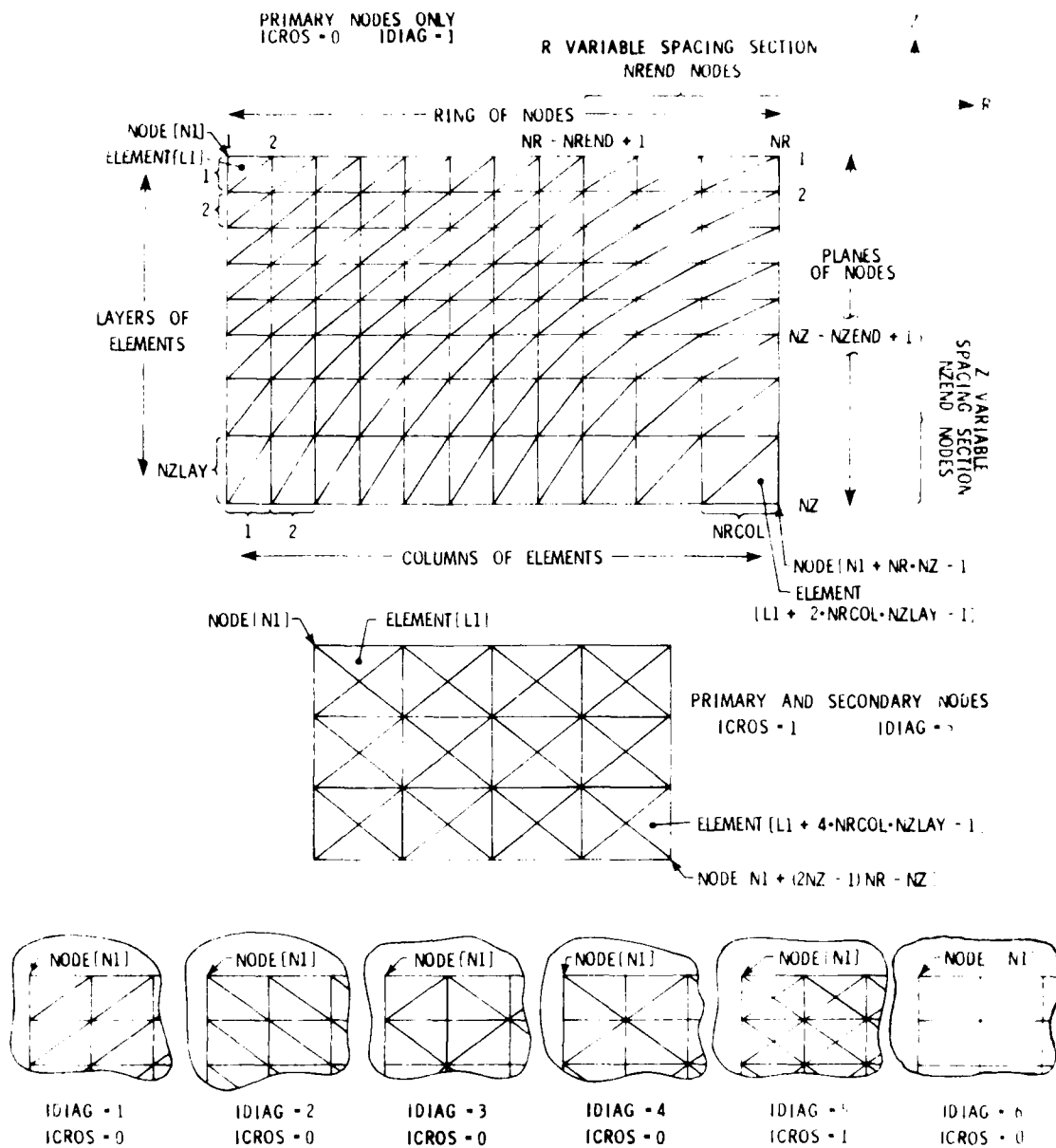


Figure 12. Flat Plate Geometry

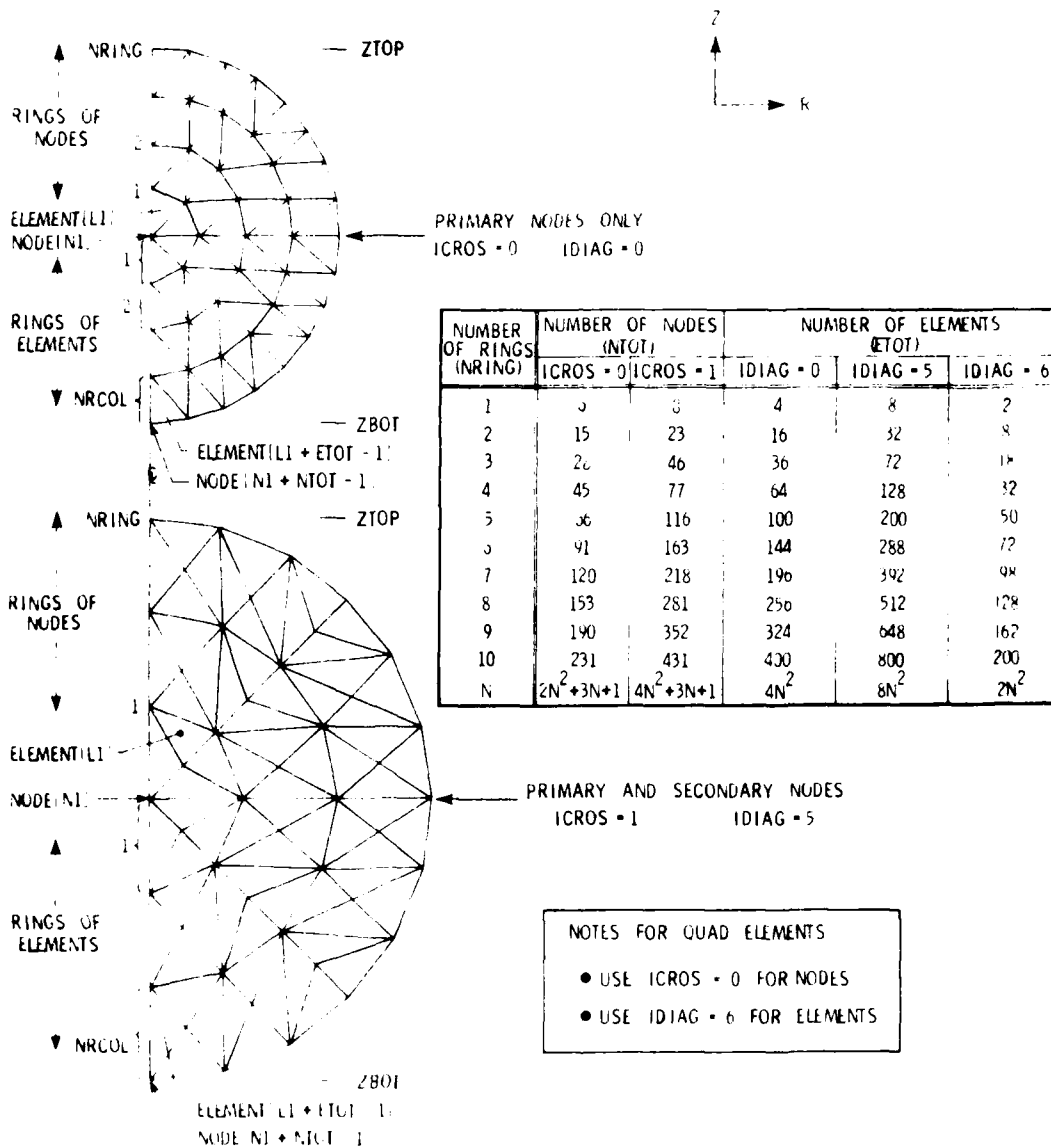
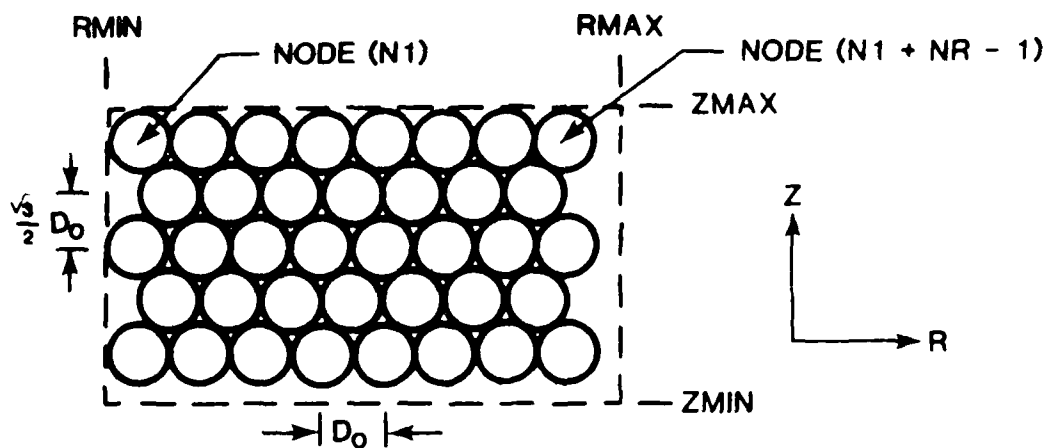


Figure 13. Sphere Geometry



D_0 = NABOR NODE DIAMETER
 NR = MAX NUMBER OF NODES IN R DIRECTION
 NZ = NUMBER OF ROWS OF NODES
 $NR = (R_{MAX} - R_{MIN}) / D_0$
 $NZ = (Z_{MAX} - Z_{MIN} - D_0) / (\frac{\sqrt{3}}{2} D_0) + 1$

Figure 14. NABOR Node Geometry

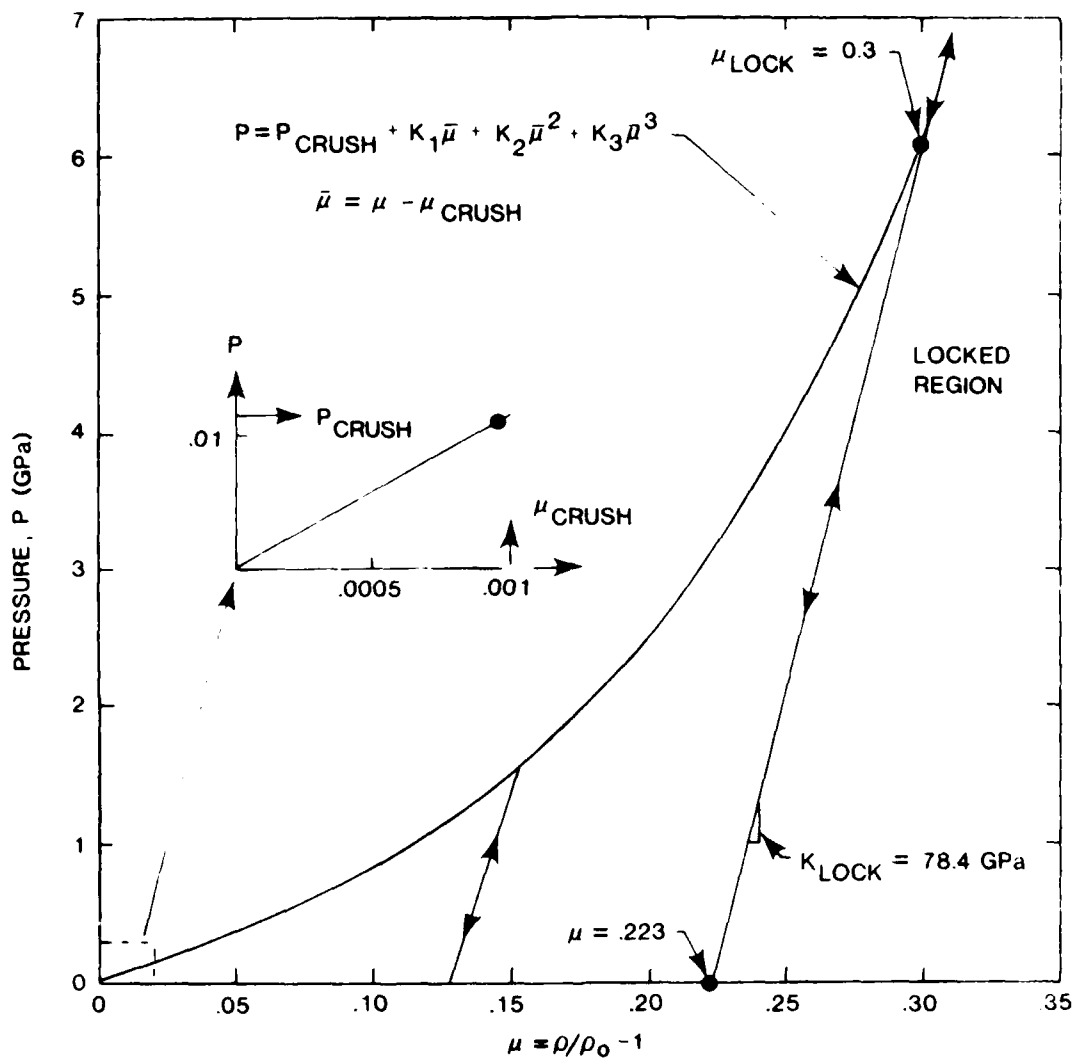


Figure 15. Pressure Model for Crushable Solids. Specific Data Shown are for Concrete

INPUT DATA FOR THE PREPROCESSOR

The function of the Preprocessor is to define the initial geometry and velocity conditions. The descriptions which follow are for the data in Figure 1. Consistent units must be used and the unit of time must be seconds.

Description Card (2I5,A60) —

CASE = Case number for run identification.

TYPE = $\begin{cases} 1 \text{ specifies a Preprocessor run only.} \\ 2 \text{ specifies a Preprocessor and Main Routine Run.} \end{cases}$

DESCRIPTION OF PROBLEM = Description provided by user.

Miscellaneous Card (16I5) —

GEOM = $\begin{cases} 1 \text{ specifies axisymmetric geometry} \\ 2 \text{ specifies plane strain geometry} \\ 3 \text{ specifies one-dimensional geometry (cartesian)} \\ 4 \text{ specifies plane stress geometry} \end{cases}$

PRINT = $\begin{cases} 0 \text{ will not print individual data for each node and element} \\ 1 \text{ will print individual data} \end{cases}$

SAVE = $\begin{cases} 0 \text{ will not write Preprocessor data on restart tape} \\ 1 \text{ will write Preprocessor data on restart tape} \end{cases}$

NMAS = Number of concentrated masses to be input separately.

NRIG = Number of systems of nodes which move as rigid system.

NCHNK = Number of groups of elements for which subsystem data are requested.

NSLID = Number of sliding surfaces.

- IZR = 1 gives a rigid frictionless surface on the positive side of the plane described by $z = 0$. If the equations of motion cause a node to have a negative z coordinate, the z coordinate and velocity are set to zero. If IZR = 0 this option is not used.
- SPLIT = 0 will perform the sliding surface computations after the updated velocities and displacements are determined from the usual equations of motion. Contact is established as long as the slave node interferes with the master surface before the velocities and displacements are adjusted in the sliding surface routines. This option is the most reliable and should be used for complicated sliding surfaces which include double pass options and intersecting sliding surfaces. It must be used for the eroding interface option. For relatively low velocity impact problems, where there is limited deformation, this option can introduce significant errors in the form of excessive deformation and internal energy.
- SPLIT = 1 will perform the sliding surface computations after the updated velocities are determined but before the updated displacements are determined. This should be used if the sliding surfaces are relatively simple. Contact is first established when the slave node interferes with the master surface. Thereafter, a slave node is considered to be in contact until the preadjusted normal velocities between the two surfaces are separating rather than closing. This approach minimizes the distance the slave node is moved to place it on the master surface and is therefore more accurate. If there are no sliding surfaces either option can be used (SPLIT = 0 or SPLIT = 1).
- NTOP = Node number of the inner radii node at the top free end of a projectile. These data, together with NBOT and NRING, are used if it is desired to obtain internal loads in a slender projectile. Use primarily for axisymmetric geometry (GEOM = 1) and one-dimensional geometry (GEOM = 3). It can also be used for normal (but not oblique) impact along the Z axis with plane strain or plane stress geometry (GEOM = 2 or 4).
- NBOT = Node number of the inner radii node at the lower end of the projectile. Use only if internal loads are desired.
- NRING = Number of rings of nodes in the projectile. Includes the secondary nodes for crossed triangle geometry. The nodal geometry must be consistent with that of the rod shape geometry shown in Figure 10. Use only if internal loads are desired.

AVEP

0 will compute individual pressures for each element. This is the primary option and should be used with triangular elements for problems involving severe distortions or explosive materials. It is also used for quad elements and one dimensional geometry.

2 will compute an average pressure for each group of two triangular elements. The elements are grouped in pairs based on the order in which they are input. Damage can be computed, but fracture is not allowed. Only solid materials (no liquids, explosives or crushable materials) and triangular elements (no quads) can be used.

4 will compute an average pressure for each group of four triangular elements (crossed triangle geometry) similar to that described above. It should be used only for cases in which the pressure is not significantly greater than the strength of the material.

Note for AVEP = 2 or 4: With the introduction of quad elements, the primary use for AVEP = 2 or 4 is when the heat conduction option is used (CDUCT = 1). When the heat conduction option is not used, quad elements are recommended instead of the AVEP = 2 or 4 option.

CDUCT

= 1 incorporates the heat conduction option. If CDUCT = 1 then the average pressure option must be used (AVEP = 2 or 4). Heat conduction is not included for CDUCT = 0.

UNIT

0 indicates the constants in the material library have English units (pound/inch/second/degree Fahrenheit).

1 indicates the constants in the material library are converted to Standard International (SI) units.

NRST

= Number of groups of nodes to have restraints redefined.

Material Data Cards — Material data can be completely defined by the user or taken from the material data library. Specific instructions are presented later. End material data with a blank card.

Projectile Scale/Shift/Rotate Card (5F10.0) —

- RSCALE** = Factor by which the r coordinates of all projectile nodes are multiplied. Applied after the coordinate shifts (RSHIFT, ZSHIFT) and before the rotation (ROTATE) described later. Must use RSCALE = 1.0 if NABOR nodes are used.
- ZSCALE** = Factor by which the z coordinates are multiplied. Must use ZSCALE = 1.0 if NABOR nodes are used.
- ROTATE** Rotation about $r = z = 0$ in the r-z plane of all projectile nodes (degrees) (positive clockwise). Applied after the coordinate shifts (RSHIFT, ZSHIFT) and the scale factors (XSCALE, ZSCALE).
- RSHIFT** Increment added to the r coordinates of all projectile nodes (length). Applied before the scale factors (RSCALE, ZSCALE).
- ZSHIFT** = Increment added to the z coordinates (length).

Node Data Cards for Projectile — These cards are required to define the projectile nodes. If a node is at the interface of the projectile and the target and contains mass from both the projectile and the target, it must be included with the projectile nodes. The node numbers must not exceed the dimension of the node arrays, and they need not be numbered consecutively or in increasing order. Specific instructions for node input data are presented later. End projectile node data with a blank card.

Target Scale/Shift/Rotate Card (5F10.0) — Same as Projectile Scale/Shift/Rotate Card except it applies to the target nodes. Must be included even if there are no target nodes.

Node Data Cards for Target — Similar to node data cards for projectile. Specific instructions are presented later. End target node data with a blank card. Include blank card even if there are no target nodes.

Element Data Cards for Projectile — These cards are required to define the projectile elements. The element numbers must not exceed the dimension of the element arrays, and they need not be numbered consecutively or in increasing order. Specific instructions are presented later. End projectile element data with a blank card.

Element Data Cards for Target — Similar to element data cards for projectile. Specific instructions are presented later. End target element data with a blank card. Include blank card even if there are no target elements.

Concentrated Mass Cards (15, 5X, F10.0) — There are NMAS (defined in Miscellaneous Card) cards entered for the concentrated masses. These cards are omitted when NMAS = 0. Each card contains data for one mass. The program is currently limited to 50 concentrated masses. Concentrated masses cannot be added to NABOR nodes.

N = Node number to which the concentrated mass is added

MASS (N) = Concentrated mass added to node N

Rigid Body Identification Cards (2I5) — Each system of rigid body nodes contains one Rigid Body Identification Card and additional cards to specify the nodes. The program is currently dimensioned for a maximum of 10 rigid body systems with a maximum of 50 nodes per system. If there are no rigid body systems (NRIG = 0 in Miscellaneous Card) this group of cards is omitted. If there is more than one system of rigid body nodes, all cards for the first system are entered before the Rigid Body Identification Card for the next system is entered. Rigid body nodes must not contain any slave nodes on sliding interfaces or have nodes restrained in the z direction. For axisymmetry geometry (GEOM = 1), all rigid body nodes are restrained in the r direction. For plane strain or plane stress geometry (GEOM = 2 or 4), if any rigid body node is restrained in the r direction, then all are restrained in the r direction.

NRN = Number of rigid body nodes in the system

NRG = Number of groups of rigid body nodes to be read. If NRG = 0 the nodes are read individually.

Individual Rigid Body Nodes Cards (16I5) —

R1...RN = Individual nodes in rigid body system

NRG Grouped Rigid Body Nodes Cards (3I5) —

R1G First node in the group of rigid body nodes

RNG Last node in the group of rigid body nodes

INC Increment between nodes in the group of rigid body nodes

Chunk Data Identification Cards (2I5) — Each subsystem of element chunks for which output is desired requires a Chunk Data Identification Card and additional cards to specify the specific elements. The program is currently dimensioned for a maximum of 10 subsystems of chunks with a maximum of 50 elements per subsystem. If there are no chunk data to be obtained (NCHNK = 0 in miscellaneous card) this group of cards is omitted. Data are input in a manner similar to that of the rigid body systems described previously.

NCE = Number of elements in the subsystem

NEG = Number of groups of elements to be read

Individual Element Chunk Cards (16I5) —

E1...EN = Individual elements in subsystem

NEG Grouped Element Chunk Cards (3I5) —

E1G = First element in the group of chunk elements

ENG = Last element in the group of chunk elements

INC = Increment between elements in the group of chunk elements

Slide Line Identification Cards (8I5, 3F10.0) — Each sliding surface contains one Identification Card and cards (as required) describing the master nodes and slave nodes. The program is dimensioned for a maximum of 10 sliding surfaces which can each contain a maximum of 50 master nodes and 500 slave nodes. If there are no sliding surfaces (NSLID = 0 on Miscellaneous Card), this group of cards is omitted. If there is more than one sliding surface, all data for the first sliding surface are entered before the second Sliding Surface Identification Card is entered. The master nodes generally should include the higher-density material. It is also desirable for the master surface to have the stronger material, have equal or greater spacing than the slave nodes, and not have a convex surface toward the slave nodes.

NMN = Number of master nodes on the sliding surface

NSN = Number of slave nodes on the sliding surface. If NSN = 0, then slave nodes will be specified by the region using the Slave Node Limits Card.

NMG = Number of groups of master nodes to be read

NSG = Number of groups of slave nodes to be read

IT1		Number of velocity iterations for the slave nodes on the master surface (References 4 and 5). Errors in the velocity match lead to errors in the deviator and shear stresses, but generally not the pressure. For high-velocity impact and explosive detonation, where the pressures are much higher than the deviator and shear stresses, a relatively low value of $IT1 = 1$ or $IT1 = 2$ can be used. For lower pressure problems, higher values should be used, $IT1 = 2$ to $IT1 = 5$. The velocity iterations, and the corresponding searches on the master surface, are performed only for those slave nodes found to be in contact during the first iteration. For one-dimensional geometry ($GEOM=3$) and the eroding interface option ($ERODE > 0$), use $IT1 = 1$.
IT2	=	Number of velocity iterations of the master nodes on the slave surface. This allows a double pass to be made such that there is no interference or crossover on the sliding surface (References 4 and 5). If $IT2 = 0$, there is no second pass, and the slave nodes can be input in any order. With this option it is possible to designate interior nodes (as well as surface nodes) as slave nodes. This procedure allows elements containing slave nodes to fail completely to simulate an eroding process (Reference 4). For $IT2 > 0$, a double pass is performed, and the slave nodes must be input in a specified order. The double pass option ($IT2 > 0$) can only be used with $SEEK = 1$.
SEEK	=	{ 1 is the option used for two-dimensional ($GEOM = 1,2,4$) problems with no NABOR slave nodes. 2 is the option used when all slave nodes are NABOR nodes (NABOR nodes cannot be master nodes). 3 is the option used for one-dimensional geometry ($GEOM = 3$).
MBOT	=	Lowest number node on the bottom of the target plate when performing perforation computations with the eroding interface option ($ERODE > 0$). All nodes above the bottom surface of the plate must have lower node numbers than MBOT. This criterion is satisfied when using the flat plate generator for nodes and elements.
FRICTION	=	Coefficient of sliding friction in the r-z plane. Does not act in θ direction for relative spinning velocities.

REF VEL = Reference velocity, which when multiplied by the integration time increment, gives a reference distance. Slave nodes are considered to be associated with a particular master surface only when they are within this reference distance. It is recommended that REF VEL be 1.0 to 1.5 times the initial relative impact velocity or the detonation velocity of explosives contained in the problem.

ERODE = Erosion strain for the eroding interface option. This option is for penetration/perforation of thick plates and is activated when $ERODE > 0$. It applies to triangular elements only and should only be used when erosion is the primary mode of penetration. The algorithm and example problems are presented in Reference 6. Because total failure of the elements must be achieved by the eroding interface algorithm, it is important that EFAIL (a material property) be much greater than ERODE.

An eroding interface usually consists of two sets of slide line data. The first slide line usually designates the top surface of the plate as the master surface and the potentially eroded nodes in the projectile as slave nodes. The second slide line usually designates the outer surface of the projectile as the master surface and the potentially eroded nodes in the plate as slave nodes. This ensures that there is no cross-over of material between the projectile and the target. Under some instances it may only be possible to use the first slide line.

When using the erosion option with axisymmetric geometry ($GEOM = 1$), the radial velocities of free nodes (those whose associated elements have all eroded) are adjusted based on the corresponding axial velocity ($RDOT = .5|ZDOT|$). Therefore, the initial target velocity in the axial direction should be zero, otherwise the radial velocities would be adjusted incorrectly.

Individual Master Node Cards (16I5) — The master nodes are input individually when $NMG = 0$. The nodes must be entered in order from the first master node to the last master node along the row of nodes. When moving from the first node to the last node, the slave nodes must be to the left of the master surface. For one-dimensional geometry ($GEOM = 3$), the master node must be below (lower z coordinate) the associated slave node.

M1...MN Master nodes in proper order from M1 to MN

NMG Grouped Master Node Cards (3I5) — This option allows master nodes to be input in groups. However, the nodes must be input in the proper order, as described for the Individual Master Node Cards.

M1G = First node in the group of master nodes.

MNG = Last node in the group of master nodes.

INC = Increment between the nodes in the group of master nodes.

Individual Slave Node Cards (16I5) — The slave nodes are input individually when NSG = 0. The slave nodes must be to the left of the master surface when moving from the first master node to the last master node. If there is no double pass (IT2 = 0), the slave nodes can be input in any order. If the double pass option is used (IT2 > 0), the slave nodes must be input in the opposite direction of the master nodes. The first slave node must be near the last master node and the last slave node must be near the first master node. This means the master surface is to the left of the slave surface when moving from the first slave node to the last slave node. For one-dimensional geometry (GEOM = 3), the slave node must be above (higher z coordinate) the associated master node.

S1...SN = Slave nodes in proper order from S1 to SN

NSG Grouped Slave Node Cards (3I5) — This option allows the slave nodes to be input in groups. Restrictions on order of input are as described for the Individual Slave Node Cards.

S1G = First node in the group of slave nodes.

SNG = Last node in the group of slave nodes.

INC = Increment between nodes in the group of slave nodes.

Slave Node Limits Card — For NSN = 0 (4F10.0) — This option allows all nodes within a specified region to be designated as slave nodes. Used only if NSN = 0 on Slide Line Identification Card.

RMAX = Maximum r coordinate of slave node region.

RMIN = Minimum r coordinate of slave node region.

ZMAX = Maximum z coordinate of slave node region.

ZMIN = Minimum z coordinate of slave node region.

Restrained Nodes Identification Cards (3I5) — Each set of restrained nodes contains one Restrained Nodes Identification Card and additional cards to specify the nodes. The program does not impose any constraint on the number of sets and each set can contain as many as the node arrays can handle. If there are no restrained node sets (NRST = 0 in Miscellaneous Card) this group of cards is omitted. If there is more than one set of restrained nodes, all cards for the first set are entered before the Restrained Nodes Identification Card for the next set is entered. This input redefines the restraints on the designated nodes (it does not simply add to existing restraints).

NFN = Number of nodes in set.

NFG = Number of groups of nodes to be read. If NFG = 0 the nodes are read individually.

IR, IZ, IT = 1 restrains nodes in r, z, θ directions, respectively. Expanded description given for Line of Nodes Description Card in Node Geometry Subsection.

Individual Restrained Nodes Cards — For NFG = 0 (16I5) —

F1...FN Individual nodes to be restrained.

NFG Group Restrained Nodes Cards (3I5) —

F1G = First node in the group of nodes to be restrained.

FNG = Last node in the group of nodes to be restrained. (May be zero if there is only one node in the group.)

INC = Increment between nodes in the group of restrained nodes. (May be zero if the increment is one or if no increment is needed.)

Velocity/Detonation Card (8F10.0) — This card describes the initial velocity and/or detonation conditions. If there are interface nodes which include mass from both the projectile and the target, the velocities of these nodes are automatically adjusted to conserve momenta.

PRDOT = Projectile velocity in the r direction (distance/time).

PZDOT = Projectile velocity in the z direction.

PTDOT = Projectile velocity in the θ direction (radians/time). Must be zero if any quad elements or NABOR nodes are used.

TRDOT = Target velocity in the r direction.

- TZDOT = Target velocity in the z direction. Should be zero when the erosion option is used (ERODE >0) with axisymmetric geometry.
- TTDOT = Target velocity in the θ direction. Must be zero if any quad elements or NABOR nodes are used.
- RDET = Radial coordinate of the explosive detonation (distance)
- ZDET = Axial coordinate of the explosive detonation

Initial Integration Card (8F10.0) —

- DT1 = Integration time increment for the first cycle. This must be less than the time required to travel across the minimum dimension of each element at the sound speed of the material in that element.
- TBURN = Time at which the detonation begins at RDET, ZDET
- BETA = Ratio of compressed time to actual time. This is used to simulate quasi-static or relatively slow dynamic problems in which the problem must be run on a faster time scale. The strain-rate-dependent material models and heat conduction equations include the effect of BETA. See Reference 7 for more details. Set BETA = 1.0 for normal conditions.

Material Cards for Solids from Library (4I5, 2F5.0) — Data for some materials are available from the material library in subroutine MATLIB. The specific materials are listed as output from the Preprocessor. Library materials may be used directly without being called by this card. If they are called by this card, however, the material data will be printed as part of the output. This card also allows the user to make some decisions regarding fracture options. The user should read the comments in subroutine MATLIB to obtain the references from which the data were generated.

- MATL = Material identification number. It must be in the range of 1 through 50 and must correspond to a material number in the library.
- 0 = Code to specify library material.

- IDAM = 1 will compute material damage. The option in the library is IDAM = 0, which will not compute damage.
- IFAIL $\left\{ \begin{array}{l} = 0 \text{ will not allow failure of the material when the damage exceeds 1.0, but rather will continue to accumulate the damage. This is the option which is in the library.} \\ = 1 \text{ will allow the material to fracture partially when the damage exceeds 1.0. Partial fracture causes shear and tensile failure, so only compressive hydrostatic pressure capability remains.} \end{array} \right.$
- DFRAC = Factor by which library fracture strain constants (D1, D2, EFMIN — defined later) are multiplied. If left blank (DFRAC = 0) factor will be set to DFRAC = 1.0
- EFAIL = Equivalent plastic strain (true) which, if exceeded, will totally fail the element such that it produces no stresses or pressures. If left blank, the library value of EFAIL = 999. will govern.

5 Material Cards for Solids Input Data [4I5, 5X, F5.0, A48/4(8F10.0)] — These five cards specify all the material constants for a solid material. These cards will supersede any material library data with the same material number, MATL. Only previously undefined variables will be defined.

- DENSITY = Material density (mass/volume)
- SPH HEAT = Specific heat (work/mass/degree)
- CONDUCT = Thermal conductivity (power/distance/degree)
- ALPHA = Volumetric coefficient of thermal expansion (degree⁻¹)
- TEMP1 = Initial temperature of the material (degree)
- TROOM = Room temperature (degree)
- TMELT = Melting temperature of the material (degree)
- X1 = Extra material constant stored in the C9 array (not currently used)
- SHEAR MOD = Shear modulus of elasticity (force/area)

C1,C2,N,C3, M, C4, SMAX = Constants to describe the material strength, σ . The primary form of the strength equation is

$$\sigma = [C1 + C2 \cdot \epsilon^N] [1 + C3 \cdot \ln \dot{\epsilon}^*] [1 - T^{*M}] + C4 \cdot P \quad (1)$$

Where ϵ is the equivalent plastic strain, $\dot{\epsilon}^* = \dot{\epsilon}/\dot{\epsilon}_0$ is the dimensionless strain rate for $\dot{\epsilon}_0 = 1.0 \text{ s}^{-1}$, T^* is the homologous temperature, and P is hydrostatic pressure (compression is positive). N must be a positive number, and the thermal softening fraction, $K_T = [1 - T^{*M}]$, is set to $K_T = 1.0$ when $M = 0$. If SMAX is input as a positive number, then the maximum strength for σ is limited to SMAX. If left blank (SMAX = 0.) the strength (σ) is not limited. A more detailed description of the strength model and data is given in Reference 10.

A constant flow stress can be obtained by setting C1 to the flow stress, $N = 1.0$, and $C2 = C3 = C4 = \text{SMAX} = M = 0$. C1, C2 and SMAX have units of stress (force/area) and the others are dimensionless.

K1, K2, K3 = Cubic coefficients for the Mie-Gruneisen equation of state (force/area)

$$P = (K1\mu + K2\mu^2 + K3\mu^3) (1 - \Gamma\mu/2) + \Gamma E_s (1 + \mu) \quad (2)$$

where $\mu = \rho/\rho_0 - 1$ and E_s is internal energy per initial volume.

Γ = Gruneisen coefficient for Mie-Gruneisen equation of state. For the average pressure options (AVEP = 2,4 in the Miscellaneous Card) energy effects are not included, so it is necessary to set $\Gamma = 0$.

CL = Linear artificial viscosity coefficient (CL ≈ 0.2).

CQ = Quadratic artificial viscosity coefficient (CQ ≈ 4.0).

PMIN = Maximum hydrostatic tension allowed (force/area).

CH = Hourglass artificial viscosity coefficient for quad elements (CH ≈ 0.02).

D1...D5 = Constants for the fracture model (Reference 11).

$$\dot{\epsilon}^f = [D1 + D2 \exp^{D3\sigma^*}] [1 + D4 \cdot \ln \dot{\epsilon}^*] [1 + D5 \cdot T^*] \quad (3)$$

Where ϵ^f is the equivalent strain to fracture under constant conditions of the dimensionless strain rate, $\dot{\epsilon}^*$, homologous temperature, T^* , and the pressure-stress ratio, $\sigma^* = \sigma_m/\bar{\sigma}$. The mean normal stress is σ_m and $\bar{\sigma}$ is the von Mises equivalent stress. Expression is valid for $\sigma^* \leq 1.5$. Damage is computed from $D = \Sigma \Delta \epsilon / \epsilon^f$, and fracture is allowed to occur when $D = 1.0$.

- SPALL = Tensile spall stress (negative pressure) at which fracture can occur (force/area).
- EFMIN = Minimum fracture strain allowed. For $\sigma^* > 1.5$, ϵ^f varies linearly from ϵ^f at $\sigma^* = 1.5$ to EFMIN at $\sigma_m = \text{SPALL}$.
- X2 = Extra material constant stored in the C10 array.

Material Cards for Explosives from Library (2I5) — Similar to the cards for the solid materials in the library except that no options are provided for fracture.

3 Material Cards for Explosives Input Data (2I5, 20X, A48/6F10.0/7F10.0) — Only new variables will be defined. See solid material definitions for other variables.

- ENERGY = Initial internal energy in explosive, E_0 (energy/volume).
- DET VEL = Detonation velocity, D (distance/time).
- C1...C5 = Constants for the JWL equation of state. If left blank, a gamma law equation of state is used where

$$\gamma = \sqrt{1 + D^2 \rho / 2E_0} \quad (4)$$

For gamma law the pressure is determined from

$$P = (\gamma - 1) E / \bar{V} \quad (5)$$

For JWL the pressure is determined from

$$P = C1 \cdot (1 - C5/C2 \bar{V}) \cdot \exp(-C2 \cdot \bar{V}) + C3 \cdot (1 - C5/C4 \bar{V}) \cdot \exp(-C4 \cdot \bar{V}) + C5 \cdot E / \bar{V} \quad (6)$$

where E is internal energy per initial volume and $\bar{V} = V/V_0$ is the relative volume. $C1$ and $C3$ have the units of pressure (force/area) and $C2$, $C4$, $C5$ are dimensionless.

- X1, X2 = Extra material variables stored in arrays C6 and C7

Material Cards for Crushable Solids from Library (215, 15X, F5.0) — Similar to the cards for other library materials. Total failure is allowed through EFAIL, but fracture due to damage is not allowed.

4 Material Cards for Crushable Solids Input Data (215, 15X, F5.0, A48/3F10.0/2(8F10.0)) — These four cards specify the material constants for a crushable solid material (Reference 12). Only new variables will be defined. See previous material definitions for other variables.

C1, C4 = Constants to describe the material strength, σ

$$\sigma = C1 + C4 \cdot P \quad (7)$$

SMAX = Maximum strength allowed (force/area). If left blank (SMAX = 0.), strength (σ) is not limited.

PCRUSH,
UCRUSH,
K1, K2, K3,
KLOCK,
ULOCK = Constants to describe the pressure, P. The model, and specific data for concrete, are shown in Figure 15. The basic model can also be used for other crushable solid materials. PCRUSH, K1, K2, K3 and KLOCK have units of pressure (force/area). UCRUSH and ULOCK are dimensionless.

X1 = Extra material constant stored in the D1 array. End material input data with a blank card.

Node Geometry

Node geometry data are required for the projectile nodes and the target nodes. These data can be input as lines of nodes, various rod shapes, nose shapes, flat plates and/or spheres. The input data are summarized in Figure 3. The axial coordinate, z, is positive upward and the radial coordinate, r, is positive to the right. One-dimensional geometry (GEOM = 3) is taken along the z axis at $r = 0$.

Line of Nodes Description Card (415, 2X, 3I1, 5X, 5F10.0) — One card is required for each line of nodes to be generated. No additional cards are needed. The nodes may be numbered consecutively or incremented by INC and the nodes may be uniformly or variably spaced. Refer to Figure 8 for more details.

I = Identification number for line of nodes geometry.

N1 = Number of the first node of the line.

NN = Number of the last node of the line. Leave blank if a single node is to be generated.

INC	= Node number increment between corresponding nodes. Leave blank for consecutive numbering or if a single node is to be generated.
IR	= Radial restraint. If IR = 1, all nodes will be restrained in the radial direction. Leave blank for no restraint.
IZ	= Axial restraint. If IZ = 1, all nodes will be restrained in the axial direction. Leave blank for no restraint.
IT	= Theta restraint. If IT = 1, all nodes will be restrained in the θ direction. Leave blank for no restraint.
R1	= R coordinate of the first node.
Z1	= Z coordinate of the first node.
RN	= R coordinate of the last node. Leave blank if a single node is to be generated.
ZN	= Z coordinate of the last node. Leave blank if a single node is to be generated.
EXPAND	= Factor by which the distance between nodes is multiplied going from the first node to the last node. Leave blank for uniform spacing.

Rod Node Description Card (6I5, 3F10.0) — Two cards are required for each rod shape to be generated. Additional cards are needed for certain options. The first node is at RMIN, ZMAX, and the nodes are numbered across each layer working down. Radial restraints are provided when the inner radius lies on the axis of symmetry ($r=0$). The nodes on the top and bottom surfaces of the rod may be generated uniformly, read in individually, or computed by analytic functions. Either the primary only or both the primary and secondary (crossed triangle) nodes may be generated in the rod geometry. (Refer to Figure 10 for more details).

2	Identification number for rod nodes geometry.
N1	= Number of the first node of the rod shape.
NRING	= Number of radial rings of nodes [not including the secondary (crossed triangle) nodes if ICROS = 1]. The maximum allowed is 50.

NPLN = Number of horizontal planes of nodes [not including the secondary (crossed triangle) nodes if ICROS = 1].

IRAD = {

- 0 gives uniform radial spacing and constant z coordinates at the top and bottom of the rod.
- 1 requires all r and z coordinates at top and bottom of rod to be input individually.
- 2 requires r coordinates at the top and bottom of the rod to be input individually and z coordinates to be generated with an analytic function.
- 3 gives uniform radial spacing at the top and bottom of the rod and requires z coordinates to be input individually.
- 4 gives uniform radial spacing at the top and bottom of the rod and requires z coordinates to be generated with an analytic function.

ICROS = Crossed triangle option. If ICROS = 1, both the primary and secondary (crossed triangle) nodes are generated. Leave blank to generate the primary nodes only.

ZTOP = Z coordinate of the top surface for IRAD = 0. Leave blank for IRAD = 1, 2, 3, 4.

ZBOT = Z coordinate of the bottom surface for IRAD = 0. Leave blank for IRAD = 1, 2, 3, 4.

EXPAND = Factor by which the distance between corresponding nodes in the vertical direction is multiplied going from top to bottom. Leave blank for uniform spacing in the vertical direction.

Rod Node Radii Card for IRAD = 0 or 3 or 4 (4F10.0) —

ROTOP = Outer radius of the rod top.

RITOP = Inner radius of the rod top.

ROBOT = Outer radius of the rod bottom.

RIBOT = Inner radius of the rod bottom.

Rod Node Top Radii Card(s) for IRAD = 1 or 2 (8F10.0) —

RT(1) ... = Radius of each ring of nodes at the top of the rod. One or more
RT(NRING) cards as required.

Rod Node Bottom Radii Card(s) for IRAD = 1 or 2 (8F10.0) —

RB(1) ... = Radius of each ring of nodes at the bottom of the rod. One or
RB(NRING) more cards as required.

Rod Node Top Surface Card(s) for IRAD = 1 or 3 (8F10.0) —

ZT(1) ... = Top z coordinate of each ring of nodes. One or more cards as
ZT(NRING) required.

Rod Node Bottom Surface Card(s) for IRAD = 1 or 3 (8F10.0) —

ZB(1) ... = Bottom z coordinate of each ring of nodes. One or more cards as
ZB(NRING) required.

Rod Node Top Surface Card for IRAD = 2 or 4 (8F10.0) —

$A_0, A_1 \dots A_7$ = Coefficients of the analytical function describing the top surface
 $|z_{top} = A_0 + A_1 r + \dots + A_6 r^6 + A_7 (1 - \cos \theta)|$

Rod Node Bottom Surface Card for IRAD = 2 or 4 (8F10.0) —

$B_0, B_1 \dots B_7$ = Coefficients of the analytical function describing the bottom sur-
face $|z_{bot} = B_0 + B_1 r + \dots + B_6 r^6 + B_7 (1 - \cos \theta)|$

Note: If it is not possible to describe the node geometry of the rod with a single shape, it is possible to use multiple shapes to form a single rod. The nodes must be numbered consecutively, and the radii and the number of rings of nodes must be the same for the individual rod shapes at their interface. Also ZTOP and ZBOT for the adjoining rods should not be identical. ZTOP for the lower rod should be less than ZBOT for the upper rod by the desired nodal spacing in the z direction. If the crossed triangle option is being used, the secondary nodes between the two shapes must be generated individually or with a line of nodes.

Nose Node Description Card (6I5, 3F10.0) — One card is required for each nose shape to be generated. Additional cards are needed for certain options. The first node (N1) is the $r = 0, z = ZMIN$ node generated by the rod generator. The nose generator numbers the nodes consecutively in the clockwise direction, starting at the central node and working outward, ring by ring. The nose shapes are always generated pointing downwards. The number of rings of nodes for the nose must be one less

than the number of rings of nodes for the rod. Either primary only or primary and secondary (crossed triangle) nodes may be generated in the nose geometry. Refer to Figure 11 for more details.

- 3 = Identification number for nose nodes geometry.
- N1 = Number of the first node at the rod-nose interface.
- NRING = Number of rings [not including the secondary (crossed triangle) nodes if ICROS = 1]. The maximum allowed is 25.
- INOSE = Nose option. If INOSE = 1, a rounded nose is generated. If the length of the nose is equal to the radius, a hemispherical nose is generated. If INOSE = 2, a conical nose is generated. If INOSE = 3, a tangent ogival nose is generated. The length of the ogival nose must be greater than or equal to the radius at the nose-rod interface.
- IRAD = Radius option. If IRAD = 1, individual radii and z coordinates are input for each ring of nodes. Leave blank (IRAD=0) for uniform spacing.
- ICROS = Crossed triangle option. If ICROS = 1, both the primary and secondary (crossed triangle) nodes are generated. Leave blank to generate the primary nodes only.
- RTOP = R coordinate of the outer ring of nodes at the rod-nose interface. Leave blank for IRAD = 1.
- ZTOP = Z coordinate at the rod-nose interface and thus equal to ZBOT from the rod geometry.
- ZBOT = Z coordinate at the tip of the nose. Leave blank for IRAD = 1.

Nose Node Top Radii Card(s) for IRAD = 1 (8F10.0) —

- RT(1)... = R coordinate of each ring of nodes at the rod-nose interface (not including the central node which is on the axis of symmetry). One or more cards as required.
- RT (NRING)

Nose Node ZMIN Card(s) for IRAD = 1 (8F10.0) —

- ZB(1)... = Z coordinate at centerline of each ring of nodes at the axis of symmetry (not including the central node which is at ZTOP). One or more cards as required.
- ZB (NRING)

Flat Plate Description Card (6I5, 4F10.0) — Two cards are required for each flat plate shape to be generated. No additional cards are needed. The first node is at the RMIN, ZMAX corner of the plate and the nodes are numbered across the plate working down. Flat plates have horizontal tops and bottoms and vertical sides. They may be joined together side to side, with or without crossed triangles, if the join option is used and the node number increment is equal to the total number of nodes (primary and secondary) in the radial direction. Regions with variable nodal spacing may be included at the RMAX end and/or the ZMIN end. Refer to Figure 12 for more details.

4	=	Identification number for flat plate nodes geometry.
N1	=	Number of the first node of the plate.
INC	=	Node number increment between corresponding nodes in the vertical direction. Leave blank if the join option is not being used.
IRFIX	=	Radial restraint option. If IRFIX = 1, all nodes on the axis of symmetry are restrained radially. Leave blank for no restraint.
IJOIN	=	Join option or crossed triangle geometry (ICROS = 1). If IJOIN = 1, the generation of the first column of primary nodes is suppressed so that plates may be joined together side to side. Leave blank if only primary nodes are generated.
ICROS	=	Crossed triangle option. If ICROS = 1, both the primary and secondary (crossed triangle) nodes are generated. Leave blank to generate the primary nodes only.
RMAX	=	Maximum r coordinate of the plate.
RMIN	=	Minimum r coordinate of the plate.
ZMAX	=	Maximum z coordinate of the plate.
ZMIN	=	Minimum z coordinate of the plate.

Flat Plate Expansion Card (4I5, 10X, 4F10.0) —

NR	=	Number of nodes in the r direction [not including the secondary (crossed triangle) nodes if ICROS = 1]. The maximum allowed is 50.
NZ	=	Number of nodes in the z direction [not including the secondary (cross triangle) nodes if ICROS = 1].

NREND	=	Number of nodes in the r variable node spacing section. The node at the division between the uniform and the variable spacing sections is included in this number. Leave blank for uniform spacing in the r direction and set equal to NR for variable spacing only.
NZEND	=	Number of nodes in the z variable node spacing section. The node at the division between the uniform and the variable spacing sections is included in this number. Leave blank for uniform spacing in the z direction and set equal to NZ for variable spacing only.
RPART	=	Fractional part of the radial length occupied by the variable spacing. Leave blank for uniform spacing in the radial direction.
R-EXPAND	=	Factor by which the radial distance between nodes is multiplied in the variable spacing section moving outward. Leave blank for uniform spacing in the r direction.
ZPART	=	Fractional part of the axial length occupied by the variable spacing. Leave blank for uniform spacing in the axial direction.
Z-EXPAND	=	Factor by which the z distance between nodes is multiplied in the z variable spacing section moving downward. Leave blank for uniform spacing in the z direction.

Sphere Node Description Card (4I5, 10X, 2F10.0) — One card is required for each sphere shape to be generated. No additional cards are needed. The first node is the central node and the nodes are numbered consecutively in the clockwise direction, starting at the central node and working outwards ring by ring. Either primary only or both primary and secondary (crossed triangle) nodes may be generated in the sphere geometry. Refer to Figure 13 for more details.

5	=	Identification number for sphere nodes geometry.
N1	=	Number of the first node of the sphere.
NRING	=	Number of rings of nodes [not including the secondary (crossed triangle) node if ICROS = 1]. The maximum allowed is 25.
ICROS	=	Crossed triangle option. If ICROS = 1, both the primary and secondary (crossed triangle) nodes are generated. Leave blank to generate the primary nodes only.
ZTOP	=	Top z coordinate of the sphere
ZBOT	=	Bottom z coordinate of the sphere

NABOR Node Description Card (3I5, 15X, 5F10.0) — One card is required for each NABOR node shape to be generated. A description of the NABOR node formulation will appear in the final report for this contract. The NABOR node option is available for axisymmetric or plane strain geometry (GEOM = 1 or 2). However, there is no allowance for rotational displacements in the θ direction (about the z axis of symmetry). Only solid materials or crushable solid materials (no explosive materials) can be used as NABOR nodes, and the two different material types cannot be in contact. NABOR nodes may be used exclusively, or they may be used in conjunction with the standard nodes and elements. The mass of NABOR nodes is dependent only on the density of the material, the radial coordinate (for GEOM = 1) and the diameter of the node. They cannot accept additional mass from attached elements or input concentrated masses. The initial diameters of all NABOR nodes in a specific problem must be identical.

Figure 14 shows initial geometry for NABOR nodes. They are arranged in a hexagonal manner. The first node, N1, is upper-left, adjusted as shown. Nodes are numbered consecutively, from left to right in horizontal rows, moving downward. The even-numbered rows have one less node than the odd-numbered rows. Other orientations may be achieved by using the Rotate option in the Penetrator and/or Target Scale/Shift/Rotate Cards.

6	=	Identification number for NABOR nodes geometry.
N1	=	Number of first node.
MATL	=	Material number for the NABOR nodes.
RMAX	=	Maximum r coordinate of the NABOR node shape.
RMIN	=	Minimum r coordinate of the NABOR node shape.
ZMAX	=	Maximum z coordinate of the NABOR node shape.
ZMIN	=	Minimum z coordinate of the NABOR node shape.
NODE DIA	=	NABOR node diameter. Must be identical for all NABOR nodes. Can be left blank for subsequent NABOR node shapes.

Element Geometry

The element data are required to be consistent with the node data for the projectile and the target. Thus, a series of composite elements, rod elements, nose elements, flat plate elements, and sphere elements may be created. The element data for these shapes are entered individually in the locations identified in Figure 1. There is no limit to the number of special shapes that may be used in the projectile or the target.

If any quad elements are used, there is no allowance for rotational displacements in the θ direction (about the z axis of symmetry). The input data are summarized in Figure 4.

Series of Composite Elements Description Card (10I5) — One card is required for each series of composite elements to be generated. No additional cards are needed. Standard or crossed triangle elements are generated depending on the number of nodes input. One-dimensional elements and two-dimensional quad elements can also be generated. The elements are numbered consecutively and only one material may be used per series. For triangle and quad elements, the nodes are input in a counterclockwise manner. For one-dimensional geometry, node N1 must have a higher z coordinate than node N2. Refer to Figure 9 for more details.

- 1 = Identification number for series of elements geometry.
- NCOMP = Number of composite elements to be generated.
- MATL = Material number for the series of elements.
- N1 = Number of the first node.
- N2 = Number of the second node.
- N3 = Number of the third node. Leave blank for one-dimensional geometry (GEOM = 3).
- N4 = Number of the fourth node. Leave blank if a single triangular element is to be generated per composite element.
- N5 = Number of the fifth node for crossed triangles. Leave blank if one or two triangular elements are to be generated per composite element. Set N5 = -1 for quad elements.
- INC = Node number increment between corresponding nodes in each composite element. Leave blank if the nodes are numbered consecutively.
- L1 = Number of the first element in the series of elements

Example: To generate the elements shown at the bottom of Figure 9, the following data must be used.

ID	NCOMP	MATL	N1	N2	N3	N4	N5	INC	L1
1	4	1	106	101	102	107	0	5	501

Rod Element Description Card (7I5) — One card is required for each rod shape to be generated. Additional cards are needed for the material option. The elements are numbered consecutively across the rod, working down layer by layer. Standard, alternating diagonal, crossed triangle elements, or quad elements, may be generated. Refer to Figure 10 for more details.

2 Identification number for rod elements geometry.

N1 Number of the first node of the rod shape.

MATL = Material number for the rod elements. Leave blank if each vertical column of composite elements is to have a different material number.

NRCOL = Number of vertical columns of composite elements. Note that there is one less column of elements when compared to the number of rings of nodes. The maximum allowed is 50.

NZLAY Number of horizontal rows of composite elements.

IDIAG = Diagonal option. If IDIAG = 5, it must be used with the crossed triangle option for nodal geometry (ICROS = 1). Refer to Figure 10.

L1 = Number of the first element in the rod shape.

Material Card(s) for MATL = 0 (16I5) —

M(1... M(NRCOL) = Material number for each vertical column of composite elements. Numbered from inner column to outer column. One or more cards as required.

Nose Element Description Card (4I5, 5X, 2I5) — One card is required for each nose shape to be generated. Additional cards are needed for the material option. The elements are numbered consecutively in the clockwise direction, starting at the first node and working outwards ring by ring. Standard or crossed triangle elements, or quad elements, may be generated. Refer to Figure 11 for more details.

3 Identification number for nose elements geometry.

N1 Number of the first node of the nose shape at nose rod interface.

MATL Material number for the nose elements. Leave blank if each radial ring of composite elements is to have a different material number.

- NRCOL = Number of radial rings of composite elements. The maximum allowed is 25.
- IDIAG = Diagonal option. If IDIAG = 5, it must be used with the crossed triangle geometry for nodal geometry (ICROS = 1). Set IDIAG = 0 for standard triangular elements and IDIAG = 6 for quad elements.
- L1 = Number of the first element in the nose shape.

Material Card(s) for MATL = 0 (16I5) —

- M(1)...
M(NRCOL) = Material number for each radial ring of composite elements. One or more cards as required.

Flat Plate Element Description Card (7I5) — One card is required for each flat plate shape to be generated. No additional cards are needed. The elements are numbered consecutively across the plate, working down layer by layer. Standard, alternating diagonal, or crossed triangle elements may be generated. Refer to Figure 12 for more details.

- 4 = Identification number for flat plate element geometry.
- N1 = Number of the first node of the flat plate shape.
- MATL = Material number for the flat plate elements.
- NRCOL = Number of vertical columns of composite elements.
- NZLAY = Number of horizontal layers of composite elements.
- IDIAG = Diagonal option. If IDIAG = 5, it must be used with the crossed triangle option for nodal geometry (ICROS = 1). Refer to Figure 12.
- L1 = Number of the first element of the flat plate shape.

Sphere Element Description Card (4I5,5X,2I5) — One card is required for each sphere shape to be generated. No additional cards are needed. The elements are numbered consecutively in the clockwise direction, starting at the central node and working outwards ring by ring. Standard or crossed triangle elements, or quad elements may be generated. Refer to Figure 13 for more details.

- 5 = Identification number for sphere elements geometry.
- N1 = Number of the first node of the sphere shape.

- MATL = Material number for the sphere elements.
- NRCOL = Number of radial rings of composite elements. The maximum allowed is 25.
- IDIAG = Diagonal option. IF IDIAG = 5, it must be used with the crossed triangle option for nodal geometry (ICROS = 1). Set IDIAG = 0 for standard triangular elements and IDIAG = 6 for quad elements.
- L1 = Number of the first element of the sphere shape.

Material Card(s) for MATL = 0 (16I5) —

- M(1),
M(NRCOL) = Material number for each radial ring of composite elements. One or more cards as required.

INPUT DATA FOR THE MAIN ROUTINE

The function of the Main Routine is to perform the computations. It may be used in conjunction with the Preprocessor, or it can read initial conditions from the restart tape which has been previously generated from a Preprocessor run or another Main Routine run. The descriptions which follow are for the data in Figure 5. Consistent units must be used and the unit of the time must be in seconds.

Restart Description Card (2I5, A60) — This card is used only for restart runs. If the Main Routine is run in conjunction with the Preprocessor (TYPE = 2 on Preprocessor Miscellaneous Card), then this card is omitted.

- CASE = Case number for run.
- 3 = Code to indicate restart run.
- DESCRIPTION = Description of problem provided by the user.

Time Integration Card (2I5,7F10.0) —

- CYCLE = Cycle number at which the run begins. The cycle numbers for which restart files are written are given in the printed output of the previous run (Preprocessor or Main Routine). CYCLE = 0 if the Main Routine is used in conjunction with the Preprocessor.

CHANG	= { 0 will not allow problem size to be changed. 1 will allow the problem size to be reduced at a specified time. 2 will allow the problem size to be reduced at one time, and then increased at another time. The expansions and reductions can be performed in either order. If identical times are designated for the expansion and reduction, the reduction will be performed first. 3 will allow the problem size to be expanded at a specific time.
DTMAX	= Maximum integration time increment which will be used for the equations of motion.
DTMIN	= Minimum integration time increment allowed. If exceeded, the results will be written onto the restart tape and the run will stop.
SSF	= Fraction of the sound speed transmit time used for the integration time increment. Must be less than 1.0.
TMAX	= Maximum time the problem is allowed to run. This time refers to the dynamic response of the system, not the central processor time (CPMAX) described next. The results at time = TMAX are written onto the restart tape, and the run is discontinued.
CPMAX	= Central processor time at which the results will be written onto the restart tape and the run will stop. The time units for this input can be seconds, minutes or hours. It should coincide with the units the specific computer uses to measure central processor time.
EMAX	Upper limit for total kinetic energy. This is used for numerical instability checks. The run will stop if the kinetic energy exceeds EMAX. If left blank, EMAX will automatically be set to 1.5 times the initial total energy.
VNREF	Reference closing velocity for NABOR search routines. It should be 0.2 to 1.0 times the impact velocity (or relative closing velocity) in the problem. Lower values will cause less searching but may allow two NABOR nodes to become too close before being detected. Higher values will cause more searching but will also ensure that nodes do not become too close before being detected.

Change Drop Card for CHANG = 1 or 2 (F10.0, 13I5) — This card is used only if changes are made which reduce the size of the problem. The portions of the problem which remain are those which were input first. Common uses are to drop the explosive gases after a liner has been accelerated, or to drop the target after a projectile has perforated the target. For CHANG = 1, the problem size is reduced only and there are no expansions. For CHANG = 2, there will be problem expansions as well as problem reductions.

TDROP	=	Time at which the change (problem size reduction) occurs.
NODE	=	Total number of nodes which remain in the revised problem.
PNODE	=	Number of projectile nodes which remain in the revised problem.
ELE	=	Total number of elements which remain in the revised problem.
PELE	=	Number of projectile elements which remain in the revised problem.
NMAS	=	Number of concentrated masses which remain in the revised problem.
NRIG	=	Number of rigid systems of nodes which remain in the revised problem.
NCHNK	=	Number of subsystems of chunks of elements which remain in the revised problem.
NSLID	=	Number of sliding surfaces which remain in the revised problem.
NPLOT	=	Number of nodes, for which time-history data are written, which remain in the revised problem.
LPLOT	=	Number of elements, for which time-history data are written, which remain in the revised problem.
NFAIL	=	Number of elements which will be designated to fail totally. This type of failure sets all stresses in the element to zero. It essentially makes the element disappear except that mass is retained at the nodes.
NAB	=	Total number of NABOR nodes which remain in the revised problem.
PNAB	=	Number of projectile NABOR nodes which remain in the revised problem.

Designated Element Failure Card (1615) — This card is used only if there are elements to be totally failed (NFAIL > 0).

EF1 ... EFN = Elements to be totally failed in the revised problem

Change Add Card for CHANG = 2 or 3 (F10.0, 1115) — This card is used only if there are additions to be made to the problem. These additions can be made in conjunction with previous problem reductions (CHANG = 2) or they can be made to the original problem (CHANG = 3).

TADD = Time at which the change (problem size expansion) occurs.

NMAS = Number of concentrated masses in the expanded problem. If this is greater than the existing number of concentrated masses, the program will read input data for the additional masses. As an example for CHANG = 2, consider the case of NMAS = 3 in the initial geometry generated by the preprocessor, NMAS = 2 in the Change Drop Card and NMAS = 6 here in the Change Add Card.

The initial geometry would read three concentrated masses. These would be included in the problem until time = TDROP, at which time only the first two concentrated masses would be included (the third would be eliminated). Now, because the expanded problem will have six concentrated masses, the program needs to read data for an additional four masses (6 expanded - 2 existing = 4 required). These masses will come into effect at time = TADD.

NRIG = Number of rigid systems of nodes in the expanded problem. If this is greater than the existing number of rigid systems of nodes, the program will read input data for the additional systems of nodes.

NCHNK = Number of subsystems of chunks of elements in the expanded problem. If this is greater than the existing number of subsystems of chunks of elements, the program will read input data for the additional chunks of elements.

NSLID = Number of sliding surfaces in the expanded problem. If this is greater than the existing numbers of sliding surfaces, the program will read input data for the additional sliding surfaces.

IZR = 1 gives a rigid frictionless surface on the positive side of the plane described by $z = 0$. If the equations of motion cause a node to have a negative z coordinate, the z coordinate and velocity are set to zero. If IZR = 0 this option is not used.

SPLIT = 0 or 1. See description given for Miscellaneous Card in the Preprocessor.

NTOP, NBOT, NRING = Node geometry descriptions if internal loads are desired. See description given for Miscellaneous Card in the Preprocessor. Must be input here even if input in initial geometry.

NRST = Number of groups of nodes to have restraints redefined.

IPRNT = 1 will print individual node and element geometry of the expanded problem. Will not print data for IPRNT = 0.

Target Scale/Shift/Rotate Card for CHANG = 2 or 3 (F10.0) — This card is the same as used in Preprocessor. Applies to all target nodes in the expanded problem. Must be included even if there are no additional nodes to be input.

Additional Target Node Data for CHANG = 2 or 3 — These cards are required to define the additional nodes (for target only) for the expanded problem. Same format as used in Preprocessor. End with a blank card. Include blank card even if there are no additional target nodes.

Additional Target Element Data for CHANG = 2 or 3 — These cards are required to define the additional elements (for target only) for the expanded problem. Same format as used in Preprocessor. End with a blank card. Include blank card even if there are no additional target elements.

NMASS, NRIG, NCHNK, NSLID, NRST data read as required. Same format as used in Preprocessor.

Target Velocity Card for CHANG = 2 or 3 (30X, 3F10.0) — This card defines the nodal velocities of all target nodes in the expanded problem. See descriptions for Velocity/Detonation Card in Preprocessor. Must be included even if there are no target nodes or if no additional target nodes were input. If there are no target velocities, do not leave the card blank. Instead, input velocities as 0. Must be followed by a blank card.

Plot Card (4I5,4F10.0) —

PCYCL = Same restart cycle as specified on the Time Integration Card.

SYS = $\left\{ \begin{array}{l} 0 \text{ will not write the system data on the plot tape.} \\ 1 \text{ will write all the system data on the plot tape.} \end{array} \right.$

- NPLOT = Number of nodes for which data will be written on the plot tape. The individual nodes are specified on the Designated Nodes Cards. Program is currently dimensioned for a maximum of 20 nodes.
- LPLOT = Number of elements for which data will be written on the plot tape. The individual elements are specified on the Designated Elements Cards. Program is currently dimensioned for a maximum of 20 elements.
- DT SYS = Time increment at which the system data are written on the plot tape. These quantities do not vary as rapidly as do the individual node and element data so a larger time increment can be used.
- TSYS = Time at which the first system data are written on the plot tape. If left blank, the time at the beginning of the Main Routine run will be used.
- DT NODE = Time increment at which the individual node and element data are written on the plot tape. These quantities vary more rapidly than the system data so a smaller time increment can be used.
- TNODE = Time at which the first individual node and element data are written on the plot tape.

Designated Nodes Card (16I5) — This card is used only if there are node data to be written on the plot tape (NPLOT > 0 on the plot card).

- N1...NN = Individual node numbers for which data will be written on the plot tape. Must be in ascending order.

Designated Elements Card (16I5) — This card is used only if there are element data to be written on the plot tape (LPLOT > 0 on the plot card).

- E1...EN = Individual element numbers for which data will be written on the plot tape. Must be in ascending order.

Data Output Cards (3F10.0,6I5) — These cards are used to specify various forms of output data at selected times, and the last card must be for a time greater than TMAX even though output will not be provided for that specific time. Recall that output is automatically provided at TMAX, and a data output card need not be provided for this time. End run with a blank card.

- TIME = Time at which output data will be provided.

ECHECK	=	Code which governs the printed output. The following options are provided:
		1. If ECHECK is greater than 1000, the individual node data and element data will not be printed. Only system data such as cg positions, momenta, energies and average velocities are provided for the projectile, target and entire system. 2. If ECHECK is less than 1000, the system data and individual node data will be printed. Individual solid element data will be printed for all elements which have an equivalent plastic strain equal to or greater than ECHECK. For example, if ECHECK = 0.5, all elements with equivalent plastic strains equal to or greater than 0.5 will have data printed. If ECHECK = 999, no element data will be printed.
RDAMP	=	Radial damping constant, C_D in equation (38) of Reference 1. This damping acts until the time specified in the following Data Output Card. RDAMP = 0 for GEOM=2,3,4 and axisymmetric geometry when no spin is present. For problems involving spin, Reference 1 should be consulted.
SAVE	=	1 will write results on restart tape for possible restart runs or state plots. Will not write results if left blank.
LOAD	=	1 will compute and print internal loads in a cylindrical projectile. This option can only be used if NTOP, NBOT and NRING are properly defined in the Miscellaneous Card of the Preprocessor. Will not compute if left blank.
CHUNK	=	1 will compute and print data for the subsystems (chunks of elements) specified in the Preprocessor. Will not compute if left blank.
BURN	=	{ 0 will print all explosive element data if ECHECK < 1000. 1 will print only those explosive elements which have been fully detonated if ECHECK < 1000. 2 will not print any explosive element data.
NDATA		Interval of cycles at which cycle data will be printed. If NDATA = 2, cycle data will be printed for every other cycle (2, 4, 6, etc.). If left blank, cycle data will be printed for every cycle.
PLOT	=	1 will give a printer plot of the node geometry if NABOR nodes are used.

INPUT DATA FOR THE POSTPROCESSOR

The function of the Postprocessor is to provide plots of the results in the form of state plots and time plots. The state plots show results for the entire system at a specified time, and the time plots show results for a specified variable as a function of time.

State Plots

Input data for state plots are summarized in Figure 6. Included is the capability to plot geometries, velocity vectors, contours of several variables, various jet characteristics and behind target debris. Plots can be requested in the order of increasing time and cycle numbers. The plots can be requested by either time or cycle number. By using the time option it is possible to request plots without having access to the output from the Main Routine. The times at which data are requested must simply coincide with those specified on the Data Output Cards of the Main Routine. End state plot data with a blank card.

Geometry Plot Card (2I5, F10.0, 4I2, 22X, A30) —

- | | | | | | | | | |
|--------|---|---|---|--|---|---|---|--|
| 1 | = | Code to specify geometry plot. | | | | | | |
| CYCLE | = | Cycle number of the plot which is desired. The cycle numbers of the data written on the restart tape are given in the printed output of the Preprocessor and the Main Routine. If CYCLE = 0 the plots are requested on the basis of time. | | | | | | |
| TIME | = | Time of the plot which is desired. Plots can be requested by either TIME or CYCLE. | | | | | | |
| AXES | = | <table border="0"><tr><td>{</td><td>0 will use the r and z axes from the previous plot. This option allows deformed geometry to be plotted together with contours or velocity vectors, for instance.</td></tr><tr><td>{</td><td>1 will automatically compute the r and z axes to include all nodes. The vertical axis is specified to be 10 units, and the horizontal axis is as required, using the same scale as the vertical axis.</td></tr><tr><td>{</td><td>2 will read the coordinate limits of the plot.</td></tr></table> | { | 0 will use the r and z axes from the previous plot. This option allows deformed geometry to be plotted together with contours or velocity vectors, for instance. | { | 1 will automatically compute the r and z axes to include all nodes. The vertical axis is specified to be 10 units, and the horizontal axis is as required, using the same scale as the vertical axis. | { | 2 will read the coordinate limits of the plot. |
| { | 0 will use the r and z axes from the previous plot. This option allows deformed geometry to be plotted together with contours or velocity vectors, for instance. | | | | | | | |
| { | 1 will automatically compute the r and z axes to include all nodes. The vertical axis is specified to be 10 units, and the horizontal axis is as required, using the same scale as the vertical axis. | | | | | | | |
| { | 2 will read the coordinate limits of the plot. | | | | | | | |
| ORIENT | = | <table border="0"><tr><td>{</td><td>0 will specify the z axis as the vertical axis and the r axis as the horizontal axis.</td></tr><tr><td>{</td><td>1 will specify the r axis as the vertical axis and the z axis as the horizontal axis.</td></tr></table> | { | 0 will specify the z axis as the vertical axis and the r axis as the horizontal axis. | { | 1 will specify the r axis as the vertical axis and the z axis as the horizontal axis. | | |
| { | 0 will specify the z axis as the vertical axis and the r axis as the horizontal axis. | | | | | | | |
| { | 1 will specify the r axis as the vertical axis and the z axis as the horizontal axis. | | | | | | | |

SIDE	= {	0 will plot the grid on the actual r coordinates.
		1 will plot the grid on the negated r coordinates only.
		2 will plot the grid on both the actual and negated r coordinates.
		3 will not plot the grid.
EDGE	= {	0 plots no outline around the edges.
		1 plots an outline on the negated r coordinate only.
		2 plots an outline on both the actual and negated r coordinates.
		3 plots an outline on the actual r coordinates only.
		-1 is same as EDGE = 1 except outlines are also included between different materials.
		-2 is same as EDGE = 2 except outlines are also included between different materials.
		-3 is same as EDGE = 3 except outlines are also included between different materials.
FAIL	=	1 will plot star in center of fractured (partially failed element). Will not plot star if left blank.
NODE	= {	0 will not plot individual node points.
		1 will plot node points on negated r coordinates only.
		2 will plot node points on both the actual and negated r coordinates.
		3 will plot node points on actual r coordinates only.
		-1 is same as NODE = 1 except projectile nodes are drawn as a plus sign and target nodes are drawn as a diamond.
		-2 is same as NODE = 2 except nodes are drawn as symbols instead of points.
		-3 is same as NODE = 3 except nodes are drawn as symbols instead of points.
TITLE	-	Title printed on the plot.

Plot Limits Cards for Axes = 2 (4F10.0) — This card specifies the portion of the problem which is plotted. Regions beyond those specified are not plotted. The vertical axis is scaled to 10 units and the horizontal is as required. The scale factor used will be a multiple of 1, 2, 3, 5, or 8 per axis unit.

RMAX = Maximum r coordinate included in the plot.

RMIN = Minimum r coordinate included in the plot.

ZMAX = Maximum z coordinate included in the plot.

ZMIN = Minimum z coordinate included in the plot.

Velocity Vector Plot Card (2I5, F10.0, 5I2, 10X, F10.0, A30) — Only previously undefined variables are defined. See Geometry Plot Card description for others.

2 = Code to specify velocity vector plot.

ARROW = 1 will place arrowheads on the velocity vectors. Leave blank for no arrowheads.

VSCALE = Velocity which will give a velocity vector which has a length of 1.0 using the scale of the plot. If left blank, VSCALE will automatically be determined to give the longest vector a length of two percent of the length of the vertical axis.

Plot Limits Card for AXES = 2 (4F10.0) — This card is the same as described for the geometry plots.

Contour Plot Card (2I5, F10.0, 7I2, 16X, A30) — This card requests contour plots of element variables. Contours are determined by first computing the variable quantities at the nodes (i.e., the nodal pressure is the average of the pressures of all elements which contain the node). Then the contours are drawn through the nodal quantities. Only previously undefined variables are defined. See Geometry and Velocity Plot Cards for others.

TYPE = Code to specify which variable is requested. Must be in the range of 3-10. See Figure 6 for description of variables.

NLINE = Number of contours to be plotted. If NLINE = 0, six contours will be plotted at values of 5, 20, 40, 60, 80 and 95 percent of the range between the minimum and maximum variable quantity limits.

SYMBOL = Increment at which symbols are placed on contour lines. **SYMBOL** = 1 will place symbols at the forward end of each contour line within an element, and **SYMBOL** = 5 will place symbols at the forward end of every fifth element, etc. **SYMBOL** = 0 will place only one symbol on the line.

PRINT = 1 will print the nodal quantities of the specified variable on the output of the Postprocessor. Leave blank for no printed nodal output.

Plot Limits Card for AXES = 2 (4F10.0) — This card is the same as described for the geometry plots.

Contour Specification Card(s) (8F10.0) — Used only for **NLINE** > 0 on Contour Plot Card.

C1 ... CN = Magnitude of contours to be plotted

One-Dimensional Plot Card (2I5, F10.0, I2, 10X, I2, A30) — For one dimensional geometry, variables are plotted as a function of the z axis. The plot axes are divided into ten units each. Plot types must be in the range of 2-10 as shown in Figure 6. All input variables have been previously defined.

Plot Limits Card for AXES = 2 (4F10.0) —

VMAX = Maximum value of the dependent variable included in the plot

VMIN = Minimum value of the dependent variable included in the plot

ZMAX = Maximum z coordinate included in the plot

ZMIN = Minimum z coordinate included in the plot

Jet Characteristics Plot Card (2I5, F10.0, 2I2, 26X, A30) — This card requests plots of various jet characteristics for explosively formed penetrators, hemi charges and shaped charges. Only data from the projectile nodes and masses are plotted. This allows meaningful plots to be obtained before the explosive gases, etc., are discarded. These plots have a vertical axis of 10 units and a horizontal axis of 10 units. Only previously undefined variables are defined. See Geometry Plot Card for others.

TYPE = Code to specify which plot is requested. Must be in the range of 11-17. See Figure 6 for description of the options. Plots for one-dimensional runs may also be obtained for **TYPE** = 11-15.

ACCUM = $\left\{ \begin{array}{l} 0 \text{ will accumulate mass, momentum and kinetic energy from the} \\ \text{slower end of the jet} \\ 1 \text{ will accumulate from the faster end (tip) of the jet} \end{array} \right.$

Plot Limits Card for AXES = 2 and TYPE = 11-15 (4F10.0) —

VMAX = Maximum value of the dependent variable
VMIN = Minimum value of the dependent variable
 $\dot{Z}/Z$ MAX = Maximum value of the independent position or velocity variable
 $\dot{Z}/Z$ MIN = Minimum value of the independent position or velocity variable

Plot Limits Card for AXES = 2 and TYPE = 16-17 (4F10.0) —

RMAX = Maximum r coordinate included in the plot
RMIN = Minimum r coordinate included in the plot
 $\dot{R}/Z$ MAX = Maximum velocity included in the plot
 $\dot{R}/Z$ MIN = Minimum velocity included in the plot

Behind Target Debris Plot Card (2I5, F10.0, 4I2, 12X, F10.0, A30) — This card requests plots of behind target momentum, kinetic energy, mass, or nodal velocity. Only velocities in the R-Z plane are included. The distribution plotted can be either that present at a flat collector plate or the angular distribution at infinity. The collector plate model plots momentum/unit area, kinetic energy/unit area, mass/unit area, and net nodal velocity versus plate position. The angular distribution model plots momentum/sterradian, kinetic energy/sterradian, mass/sterradian, and net nodal velocity versus angle from the z axis. Only previously undefined variables are defined.

TYPE = Code to specify which plot is requested. Must be in the range 18-21. See Figure 6 for description of the options.

OPTION = $\left\{ \begin{array}{l} 1 \text{ will plot results for flat collector plate} \\ 2 \text{ will plot results for angular distribution} \end{array} \right.$

VCUT = $\left\{ \begin{array}{l} 0 \text{ will use a cutoff velocity of one-tenth the most negative } z \text{ velocity.} \\ 1 \text{ will read the cutoff velocity from the Plot Limits Card} \end{array} \right.$

NBIN = Number of collector bins to sum variables. Must be in range of 1-99. NBIN = 0 will give 90 angular bins (of one degree each) for angular distribution model.

NPART = $\left\{ \begin{array}{l} 0 \text{ will use all the nodes} \\ 1 \text{ will use projectile nodes only} \\ 2 \text{ will use target nodes only} \end{array} \right.$

ZPLATE = Z coordinate of the flat collector plate for OPTION = 1.

Plot Limits Card (5F10.0)

- VMAX = Maximum value of the dependent variable. If VMAX = VMIN = 0, then the values of VMAX and VMIN will be computed from the data and the vertical scale will be automatically determined.
- VMIN = Minimum value of the dependent variable. Automatically determined when VMAX = VMIN = 0.
- HMAX = Maximum r coordinate of collector plate for OPTION = 1, or maximum angle (degrees) for OPTION = 2.
- HMIN = Minimum r coordinate of collector plate for OPTION = 1, or minimum angle (degrees) for OPTION = 2.
- V-CUTOFF = Cutoff velocity for VCUT = 1. Nodes with a net velocity less than the cutoff velocity will not be included in the data for the plots. For VCUT = 0, V-CUTOFF will be assigned a cutoff velocity of one-tenth the most negative z velocity.

Extrapolated Geometry Plot Card (2I5, F10.0, 6I2, 18X, A30) — This option allows the user to obtain extrapolated geometry plots at times much greater than were computed. Similar options as for Geometry Plot Card (TYPE = 1). Only previously undefined variables are defined.

- T-EXTRAP = Extrapolated time for which the geometry is desired. Nodal positions are based on straight line extrapolation using positions and velocities from the specified cycle (or time).

Time Plots

Input data for time plots are summarized in Figure 7. System Plot Cards should be input first, followed by Individual Node and Individual Element Plot Cards. The variables are plotted as a function of time. Program is currently dimensioned such that system data can be plotted for a maximum of 500 time increments, and the node and element data for a maximum of 1000 time increments. The plot axes are divided into ten units each. End with a blank card.

System Plot Cards (2I5, 5X, F5.0, 4F10.0, A18) — These cards request plots of the system variables. Each plot contains data for the projectile, the target and the total system (projectile plus target). These data must have been previously written on the plot tape by setting SYS = 1 on the Plot Card in the Main Routine.

- TYPE = Code describing the type of plot. See Figure 7 for description of type. Must be in range of 1 through 17.

AXES	=	$\begin{cases} 0 & \text{will automatically select coordinates to include max and min} \\ & \text{values of variable for total duration of time} \\ 1 & \text{will read the coordinate limits of the plot} \end{cases}$
SCALE	=	Factor by which the variables are multiplied before plotting
TMAX	=	Maximum time included on horizontal axis if AXES = 1 (time)
TMIN	=	Minimum time included on horizontal axis if AXES = 1 (time)
VMAX	=	Maximum variable included in vertical axis if AXES = 1
VMIN	=	Minimum variable included on vertical axis if AXES = 1
TITLE	=	Title written on the plot

Individual Node Plot Cards (3I5, F5.0, 4F10.0, A18) — These cards request plots of nodal variables. These data must have been previously written on the plot tape by specifying the requested nodes on the Designated Nodes Card in the Main Routine. Only previously undefined variables are defined.

TYPE = Code describing the type of plot. See Figure 7 for description of types. Must be in the range of 18 through 30. Note that acceleration data (TYPE = 24-26) may be incorrect for sliding surface and rigid body nodes.

NODE = Specific node for which plot data are requested.

Individual Element Plot Cards (3I5, F5.0, 4F10.0, A18) — These cards request plots of element variables. These data must have been previously written on the plot tape by specifying the requested elements on the designated Elements Cards in the Main Routine. Only previously undefined variables are defined.

TYPE = Code describing the type of plot. See Figure 6 for description of types. Must be in the range of 31 through 39. The only data available for explosive elements are pressure (TYPE = 31) and Internal Energy (TYPE = 38).

ELE = Specific element for which plot data are requested

PROGRAM STRUCTURE AND FILE DESIGNATION

A hierarchy chart for the Preprocessor and Main Routine is shown in Figure 16. The Postprocessor for state plots and the Postprocessor for time plots are two separate programs. The corresponding hierarchy charts are shown in Figures 17 and 18. The grouping of subroutines is given in Table 1 and the required groups at subroutines for various types of runs are given in Table 2.

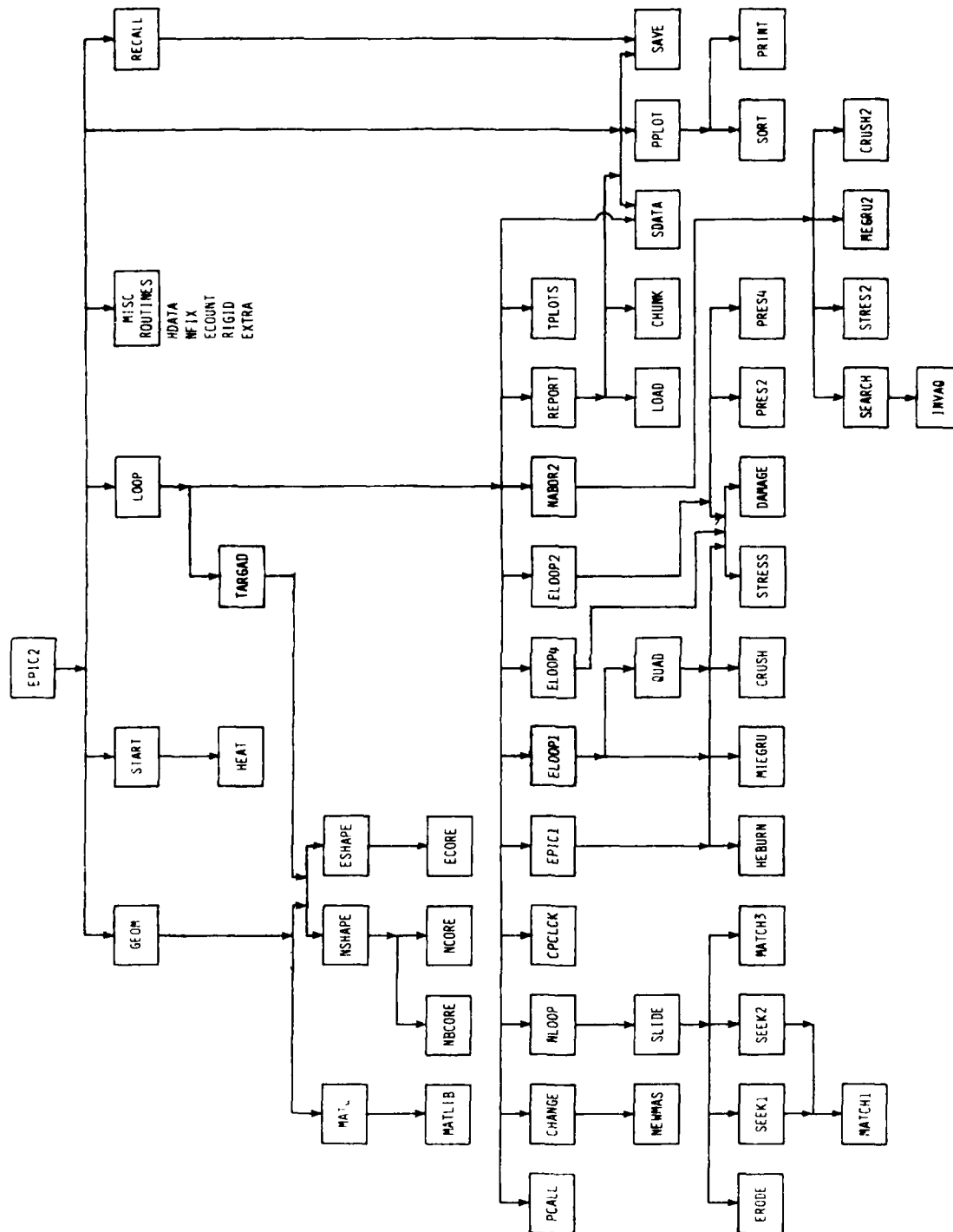


Figure 16. Hierarchy Chart for the Preprocessor and Main Routine

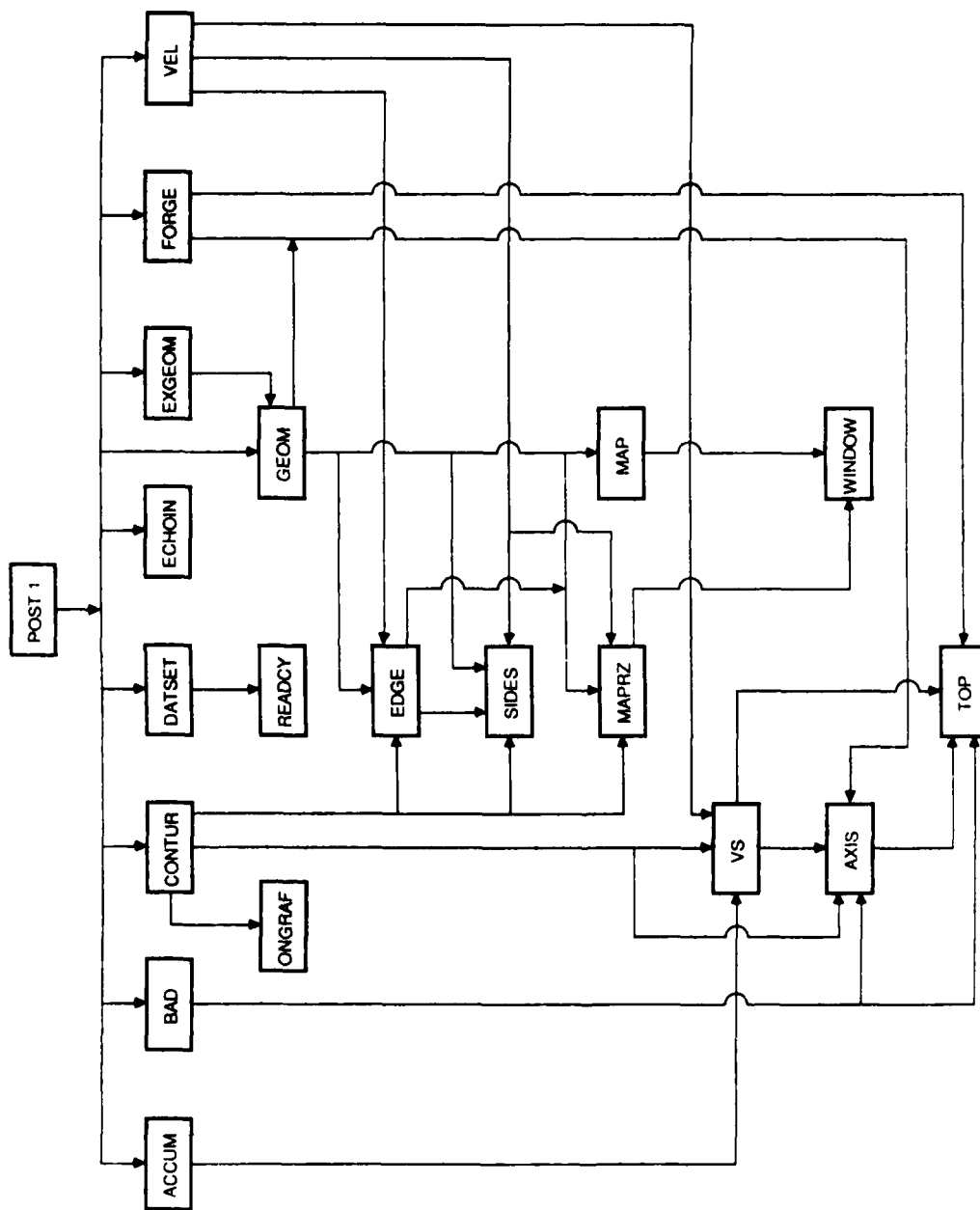


Figure 17. Hierarchy Chart for the State Plots Postprocessor

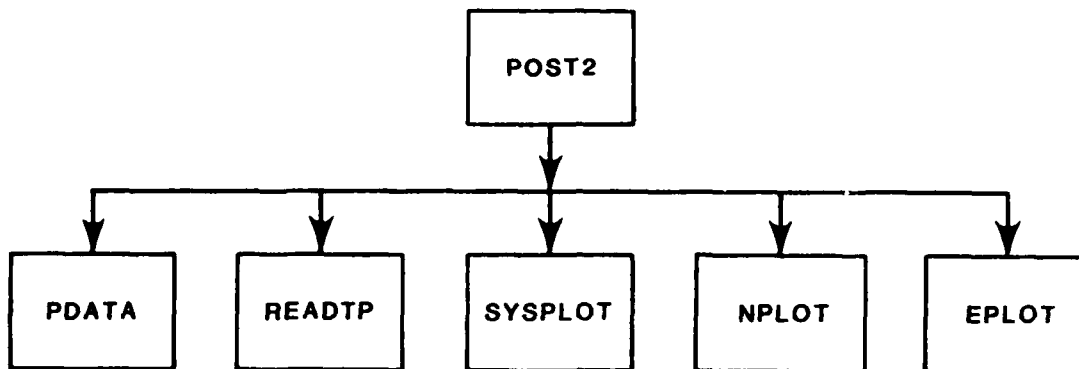


Figure 18. Hierarchy Chart for the Time Plots Postprocessor

The file designations are as follows:

ITAT	= 4 copy of Target Addition Cards from Input file when Target Addition option is used.
IN	= 5 Input file
IOUT	= 6 Output file
IPLTIN	= 7 Restartable plot tape for time plots, which is read by the Main Routine
ITAPLT	= 8 Plot tape for time plots written by the Main Routine
ITAPIN	= 9 Restart tape ready by the Main Routine
ITAPOT	= 9 Restart tape generated by the Preprocessor and/or Main Routine. When ITAPOT = ITAPIN the restart run writes data on the same tape from which it read the restart data. Previous cycle data are also saved on the tape. If ITAPOT $\neq$ ITAPIN, the restart data are written on a different tape.

Table 1. Subroutine Groupings for the EPIC-2 Code

EPIC2	PREP	MAIN	NABOR	POST1	POST2
EPIC2 ECORE ECOUNT ESHAPE EXTRA HDATA NBCORE NCORE NFI NSHAPE PLOT PRINT RIGID SAVE SDATA SORT	GEOM HEAT MATL MATLIB START	CHANGE CHUNK CPCLCK CRUSH DAMAGE ELOOP1 ELOOP2 EPIC1 ERODE HEBURN LOAD LOOP MATCH1 MATCH3 MIEGRU NEWMAS NLOOP PCALL PRES2 PRES4 QUAD RECALL REPORT SEEK1 SLIDE STRESS TARGAD TPLOTS	CRUSH2 INVAQ MEGRU2 NABOR2 SEARCH SEEK2 STRES2	POST1 ACCUM AXIES CONTUR DATSET ECHOIN EDGE FORGE GEOM MAP MAPRZ ONGRAF READCY SIDES TOP VEL VS WINDOW	POST2 EPLOT NPLOT PDATA READTP SYMPLOT

Table 2. Required Groups of Subroutines for Various Types of Runs

TYPE OF RUN	REQUIRED SUBROUTINE GROUPS					
	EPIC2	PREP	MAIN	NABOR	POST1	POST2
PREPROCESSOR ONLY	X	X				
PREPROCESSOR AND MAIN ROUTINE (NO NABOR NODES)	X	X	X			
PREPROCESSOR AND MAIN ROUTINE (WITH NABOR NODES)	X	X	X	X		
RESTART (NO NABOR NODES)	X		X			
RESTART (WITH NABOR NODES)	X		X	X		
STATE PLOTS					X	
TIME PLOTS						X

INSTRUCTIONS FOR CHANGING PROGRAM DIMENSIONS

The dimensions of the Preprocessor and Main Routine can be changed by re-dimensioning the arrays in common blocks NODE, ELEMNT, NABOR and MISC2. The corresponding sizes of the redimensioned arrays must be placed in the DATA statement in the calling program, EPIC-2. A description of the array sizes for the DATA statement is given in subroutine GEOM. Some additional comments are as follows:

- If no elements are used, the ELEMNT arrays may be set to the minimum size $MAXL = 1$.
- If no NABOR nodes are used, the NABOR arrays may be set to the minimum size $MAXNAB = 1$.
- If NABOR nodes are used, the NODE array sizes and NABOR array sizes should be identical ($MAXN = MAXNAB$).

CENTRAL PROCESSOR TIME ESTIMATES

For various problems run on the CDC Cyber 176 computer at Eglin AFB, the EPIC-2 Main Routine has used 0.0001 to 0.0002 central processor second per cycle per element. The explosive elements require less computing time than the solid elements.

EXAMPLE PROBLEM

Input data for a copper projectile impacting a steel target are given in Figure 19. The geometry of the computed response is shown in Figure 20 and output data are shown in Figure 21.

102	2COPPER ROD	IMPACT ON STEEL PLATE AT 100,000 IN/SEC									CARD
1	1	1	0	0	0	0	0	0	0	0	CARD
1	0	1	1	1-0	999-						CARD
9	0	1	1	1-0	999-						CARD
											CARD
2	1-0										CARD
2	1	5	17	0	1	2-0	0-001		1-0		CARD
0-5			0-0		0-5	0-0					CARD
											CARD
	1-0		1-0								CARD
4	201	0	1	0	1	3-0	0-0		0-0	-1-0	CARD
19	9	7	0			0-5	1-2		0-0	1-0	CARD
											CARD
2	1	1	4	16	5	1					CARD
											CARD
4	201	9	18	8	5	301					CARD
											CARD
13	149	1	1	1	0	1	497	0-0	120000-	1-5	CARD
201	213	1									CARD
1	149	1									CARD
21	0	2	0	1	0	1	0	0-0	120000-	1-5	CARD
5	140	9									CARD
149	145	-1									CARD
	0-8		0-0		0-0		-1-0				CARD
	0-0	-100000-		0-0			0-0	0-0	0-0		CARD
	0-5E-7		0-0	1-0							CARD
0	0		1-0	-0-0000001		0-9	0-000040	1-0	0-0	0-0	CARD
0	1	1	1	1-0E-6		0-0	1-0E-7	0-0			CARD
127											CARD
823											CARD
	-0-00010		1111-		0-0	1					CARD
	-0-00020		1111-		0-0	1					CARD
1-000000			0-		0-0	1					CARD

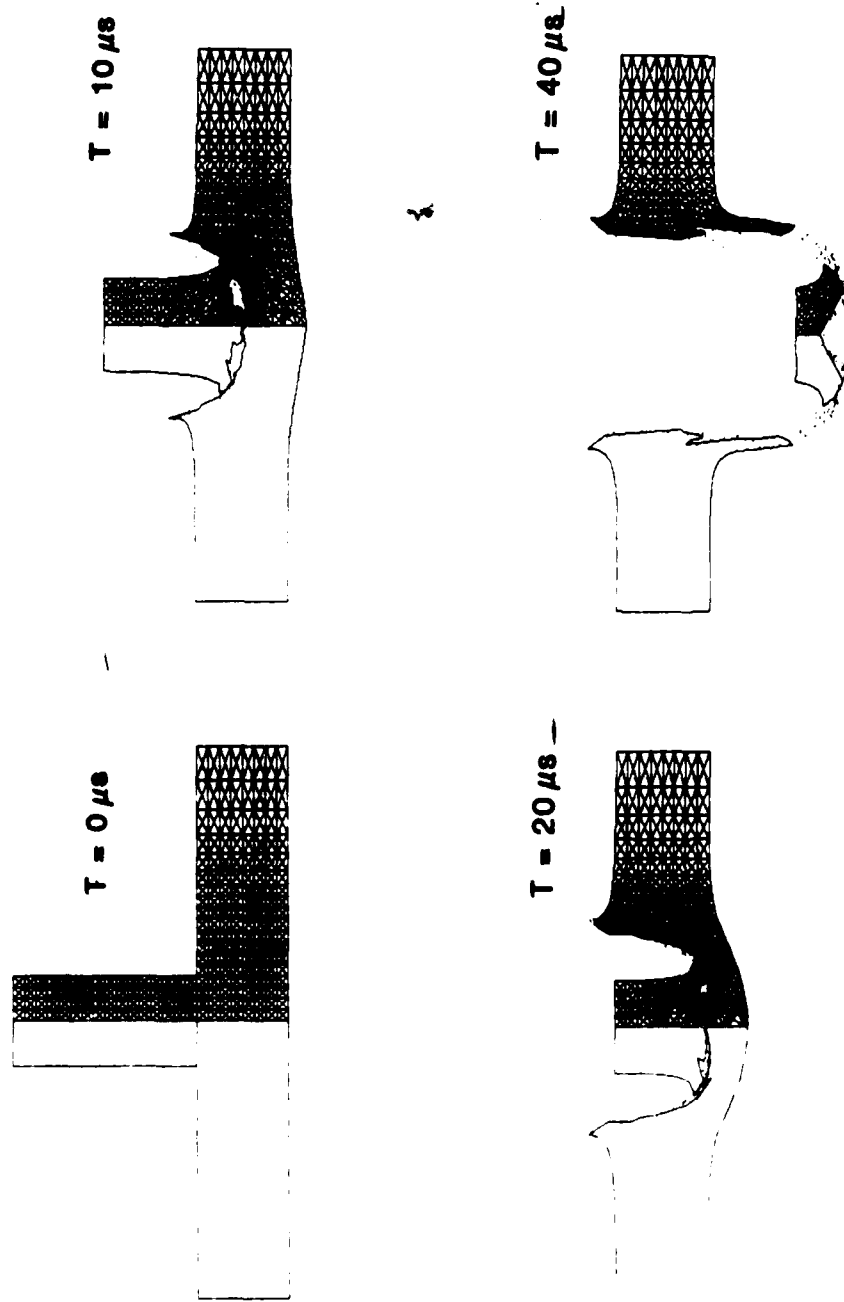


Figure 20. Computed Response of Example Problem

SYSTEM DATA FOR CYCLE 534 AT TIME = 0.400604E-04

	PROJECTILE	TARGET	TOTAL SYSTEM
MASS	= 0.131410E-02	0.206968E-01	0.220109E-01
ERODED MASS (TOTALLY FAILED)	= 0.872645E-03	0.131526E-02	0.218791E-02
TOTAL ENERGY	= 0.349938E+07	0.247590E+07	0.597528E+07
KINETIC ENERGY	= 0.320827E+07	0.140229E+07	0.461056E+07
INTERNAL ENERGY	= 0.291111E+06	0.107361E+07	0.136472E+07
PLASTIC WORK	= 0.668562E+05	0.833626E+06	0.900483E+06
MAXIMUM R COORDINATE	= 0.212466E+01	0.302742E+01	0.302742E+01
MINIMUM R COORDINATE	= 0.000000E+00	0.926403E-01	0.000000E+00
MAXIMUM Z COORDINATE	= 0.286858E+01	0.122743E+01	0.286858E+01
MINIMUM Z COORDINATE	= -0.246614E+01	-0.251750E+01	-0.251750E+01
CG IN R DIRECTION	= 0.000000E+00	0.000000E+00	0.000000E+00
CG IN Z DIRECTION	= -0.193553E+01	-0.567819E+00	-0.649475E+00
LINEAR MOMENTUM IN R DIRECTION	= 0.000000E+00	0.000000E+00	0.000000E+00
LINEAR MOMENTUM IN Z DIRECTION	= -0.812704E+02	-0.501396E+02	-0.131410E+03
ANGULAR MOMENTUM (CLOCKWISE IS +)	= 0.000000E+00	0.000000E+00	0.000000E+00
LINEAR VELOCITY IN R DIRECTION	= 0.000000E+00	0.000000E+00	0.000000E+00
LINEAR VELOCITY IN Z DIRECTION	= -0.618449E+05	-0.242257E+04	-0.597022E+04
NET LINEAR VELOCITY	= 0.618449E+05	0.242257E+04	0.597022E+04
ANGULAR VELOCITY (CLOCKWISE IS +)	= 0.000000E+00	0.000000E+00	0.000000E+00

CYCLE 534 DATA SAVED ON FILE 9 FOR RESTART AND/OR PLOTS

Figure 21. Output Data for the Example Problem

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

User instructions have been provided for the EPIC-2 code. This code can be used for a wide range of problems involving high-velocity impact, explosive-metal interaction, and analysis of various material characterization tests.

REFERENCES

1. Johnson, G.R. *EPIC-2, A Computer Program for Elastic-Plastic Impact Computations in 2 Dimensions Plus Spin*. Honeywell Inc., Hopkins, MN, Contract Report ARBRL-CR-00373, June 1978.
2. Johnson, G.R. *EPIC-2 User Manual AFATL 1983 Version*, Honeywell Inc., Edina, MN, AFATL-TR-86-54 (Technical Note), 1986. UNCLASSIFIED
3. Johnson, G.R. "Recent Developments and Analyses Associated with the EPIC-2 and EPIC-3 Codes." *Advances in Aerospace and Structures and Materials*. Edited by S.S. Wang and W.J. Renton. AD-01, ASME, 1981.
4. Johnson, G.R., D.D. Colby, and D.J. Vavrick "Three Dimensional Computer Code for Dynamic Response of Solids to Intense Impulsive Loads." *International Journal for Numerical Methods in Engineering*, 14, no. 12 (1979).
5. Johnson, G.R. "Dynamic Analysis of Explosive-Metal Interaction in Three Dimensions." *Journal of Applied Mechanics*, ASME, 103, no. 1 (March 1981).
6. Stecher, F.P. and G.R. Johnson "Lagrangian Computations for Projectile Penetration into Thick Plates." *Proceedings of 1984 International Computers in Engineering Conference*. Las Vegas, NV, August 1984.
7. Johnson, G.R. "Dynamic Analysis of a Torsion Test Specimen Including Heat Conduction and Plastic Flow." *Journal of Engineering Materials and Technology*. ASME, 103 (June 1981).
8. Johnson, G.R., "Dynamic Plane Stress Computations for Large Plastic Deformations," *Communications in Applied Numerical Methods*, Vol. 1, (1985).
9. Johnson, G.R., R.A. Stryk and J.G. Dodd "Dynamic Lagrangian Computations for Solids, With Variable Nodal Connectivity for Severe Distortions," *International Journal of Numerical Methods in Engineering*, Vol. 23, (1986).
10. Johnson, G.R. and W.H. Cook "A Constitutive Model and Data for Metals Subjected to Large Strains, High Strain Rates and High Temperatures," *Proceedings of Seventh International Symposium on Ballistics*. The Hague, The Netherlands, April 1983.
11. Johnson, G.R. and W.H. Cook "Fracture Characteristics of Three Metals Subjected to Various Strains, Strain Rates, Temperatures and Pressures," *Engineering Fracture Mechanics*, Vol. 21, no. 1 (1985).
12. Matuska, D.A., R.E. Durrett and J.J. Osborn, *Hull User Guide for Three Dimensional Linking with EPIC-3*. Orlando Technology, Inc., Shalimar, FL, ARBRL-CR-00484, July 1982.

END

12-86

DTIC