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COMOC: THERMAL ANALYSIS VARIANT

User's Manual

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Computer Program User's Manual

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16. Abstract

The Thermal Analysis Variant of the COMOC (Computational Continuum Mechanics) computer system solves problems involving transient heat conduction and convection in stationary continua spanning arbitrarily irregular two-dimensional and axisymmetric solution domains. COMOC is based upon a finite element solution algorithm for the energy equation, and solves for the transient nodal temperature distribution using a highly stable and automatic explicit integration procedure. COMOC is extensively user-oriented, requires minimal input, and no a priori knowledge concerning the stability character of the differential equation system. It can readily output computed data in user-specified format fields, that geometrically resemble the solution domain discretization (for rapid engineering evaluation). This report provides the user with complete information for applying COMOC to a specific problem.

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ABSTRACT

The Thermal Analysis Variant of the COMOC (Computational Continuum Mechanics) computer system solves problems involving transient heat conduction and convection in stationary continua spanning arbitrarily irregular two-dimensional and axisymmetric solution domains. COMOC is based upon a finite element solution algorithm for the energy equation, and solves for the transient nodal temperature distribution using a highly stable and automatic explicit integration procedure. COMOC is extensively user-oriented, requires minimal input, and no a priori knowledge concerning the stability character of the differential equation system. It can readily output computed data in user-specified format fields, that geometrically resemble the solution domain discretization (for rapid engineering evaluation). This report provides the user with complete information for applying COMOC to a specific problem.

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I. SUMMARY AND GUIDELINES

The Thermal Analysis Variant of the COMOC (Computational Continuum Mechanics) computer system can solve diverse problems involving transient heat conduction and transfer in stationary continua spanning arbitrarily irregular two-dimensional and axisymmetric spaces. COMOC embodies a finite element algorithm for solution of the energy conservation equation, and determines the transient nodal temperature distribution using a highly stable explicit integration algorithm. COMOC is highly user-oriented, including both input and output phases, and solution accuracy is automatically maintained while minimizing computer execution time. Various manual modes of operation of COMOC are user-specifiable through parameter overrides, to adapt the code to any specific requirements of a given problem. A complete description of the theoretical basis for COMOC, as well as detailed discussion concerning the various technical features of the program, are presented in Bell Report 9500-920257.*

The following general guidelines will assist the user in adapting COMOC to a specific problem.

A. DISCRETIZATION

Up to 1000 finite elements, in two-dimensional or axisymmetric space, involving up to 700 node locations may be specified. The solution domain closure and the discretization may be arbitrarily irregular. The nodes of the triangular shape finite elements must sequence in a counterclockwise fashion.

B. PROBLEM DESCRIPTION INPUT

Input phases occur at the node and element levels. Any specific initial temperature distribution is accepted, and up to 100 nodes may have fixed temperatures (identified by inputting the negative of the desired temperature). Internal heat generation is specifiable in every finite element. Each element may have one side (only), connecting the first two nodes listed for that element, on the global domain closure, where any combination of convection or fixed heat flux boundary conditions may be applied. In two-dimensional problems, convection or heat flux boundary conditions may be applied to the element surface as well, and each element may have a unique thickness.

C. THERMOPHYSICAL PROPERTIES

The thermal conductivity may have tensor properties, and all thermophysical data are specifiably temperature dependent via tables with up to twenty entries. In addition, the solution domain may consist of up to six different materials, each with its own thermophysical specifications. Each finite element of the discretization must be identified with only one material property description.

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*Baker, A. J. and P. D. Manhardt, "Finite Element Solution for Energy Conservation Using a Highly Stable Explicit Integration Algorithm," Bell Aerospace Research Report 9500-920257, October, 1972.

D. INTEGRATION INPUT

Only the initial and final values of the integration interval, the integration option (1 or 2) in COMOC, and the desired output print interval need be specified. COMOC will automatically extremize integration step size while maintaining a stable solution. Other input features allow various levels of manual control, including tighter accuracy control, marching at a fixed step size, specifying an initial minimum step size, and output at exact time stations.

E. OUTPUT

The standard subroutine provides tabular output of temperature and time derivative of temperature at the nodes for the specified output interval. The user may readily prepare a special subroutine to output these variables in a format geometrically similar to the physical shape of the problem. In either case, output is typically provided at intervals close to the requested value. By setting a parameter, and at the expense of slightly longer computer run times, output is provided at exactly the specified intervals.

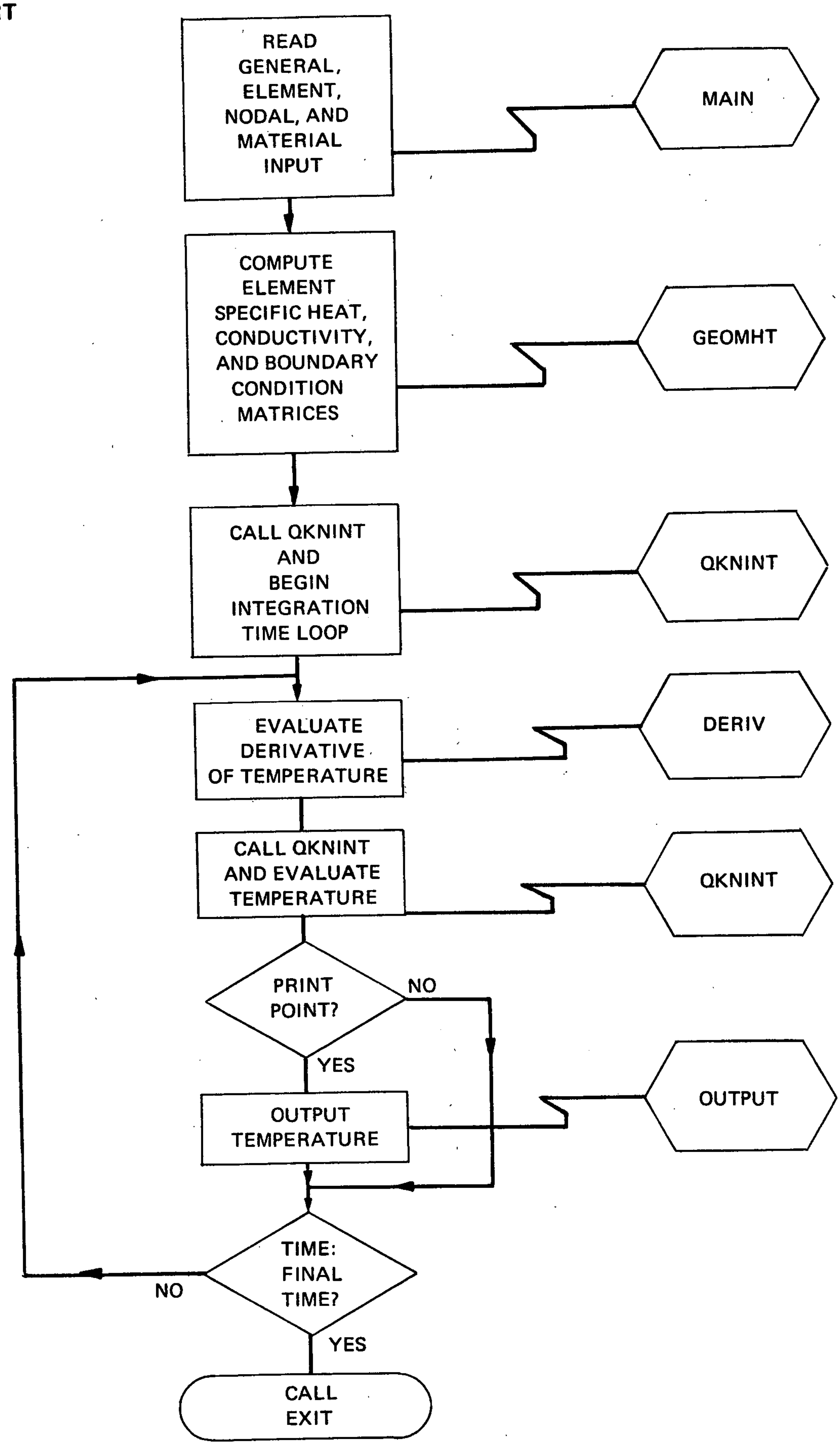
Two additional intermediate output options exist. By setting a parameter, complete printout of all matrices computed for each finite element is obtained. Additionally, complete printout of the matrix operations and assembly of the global solution vector, associated with the derivative evaluation operation within the integration algorithm, may be obtained for a user-specified number of passes through COMOC. These outputs are useful for checking that problem input has been properly prepared. All the output features are illustrated in the sample problem discussed in this manual.

COMOC employs non-dimensional dependent and independent variables throughout; therefore, input in any consistent units system is acceptable, and output will occur in that same system. The Hollerith statements in COMOC assume use of English units (Btu, hr, ft, °R). A change to ISU, or operation in a dual output mode (English and ISU), could be readily made if required.

II. DESCRIPTION OF ROUTINES AND FLOW CHARTS

A macro flow chart illustrates the overall flow of the computer program. This is followed by descriptions and flow charts of all the subroutines which constitute the Thermal Analysis Variant of COMOC.

MACRO
FLOW-CHART

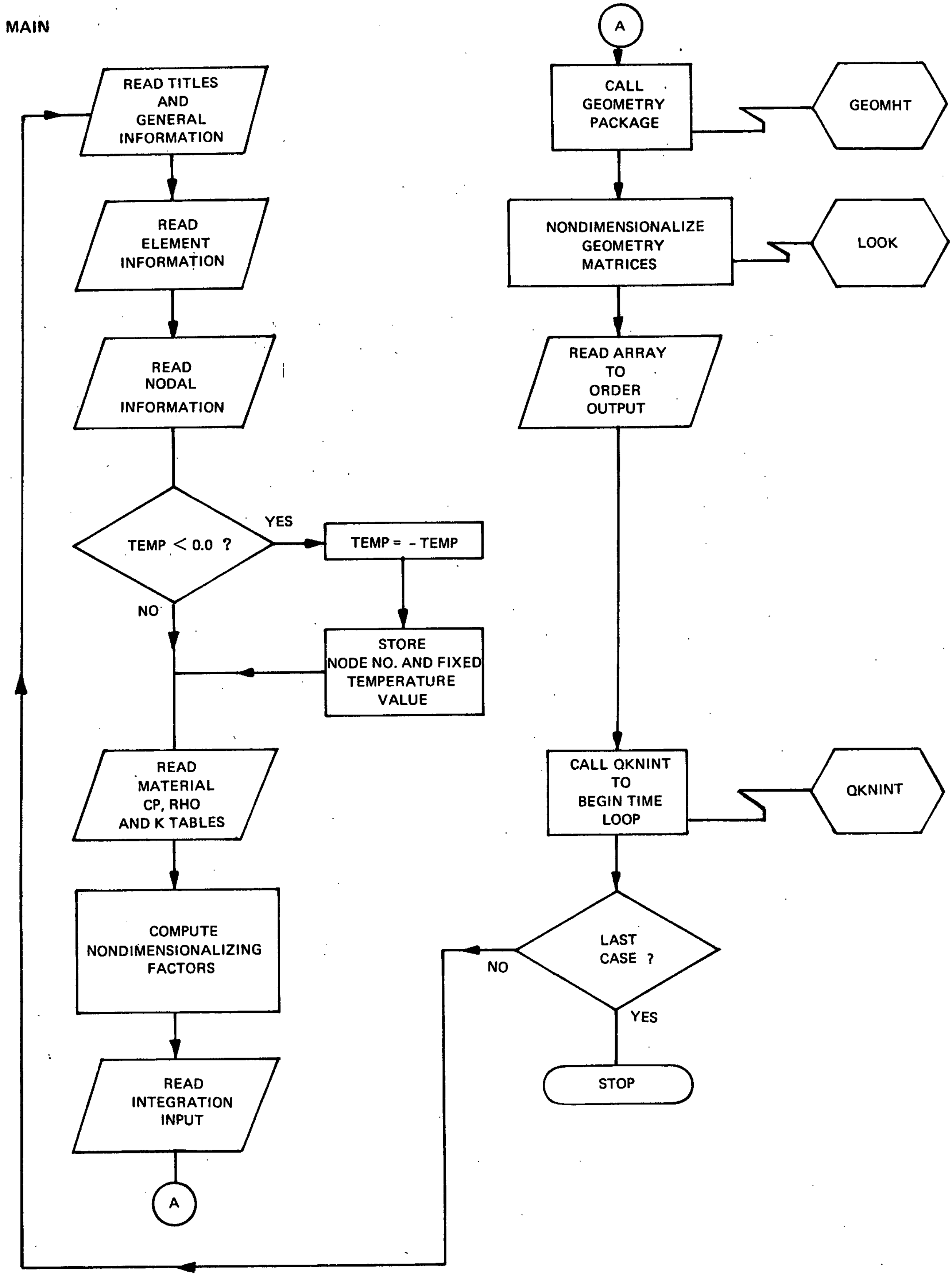


MAIN

This is the executive routine which performs all input and nondimensionalization operations and initiates the execution of the geometry and integration routines.

MICRO FLOW-CHARTS

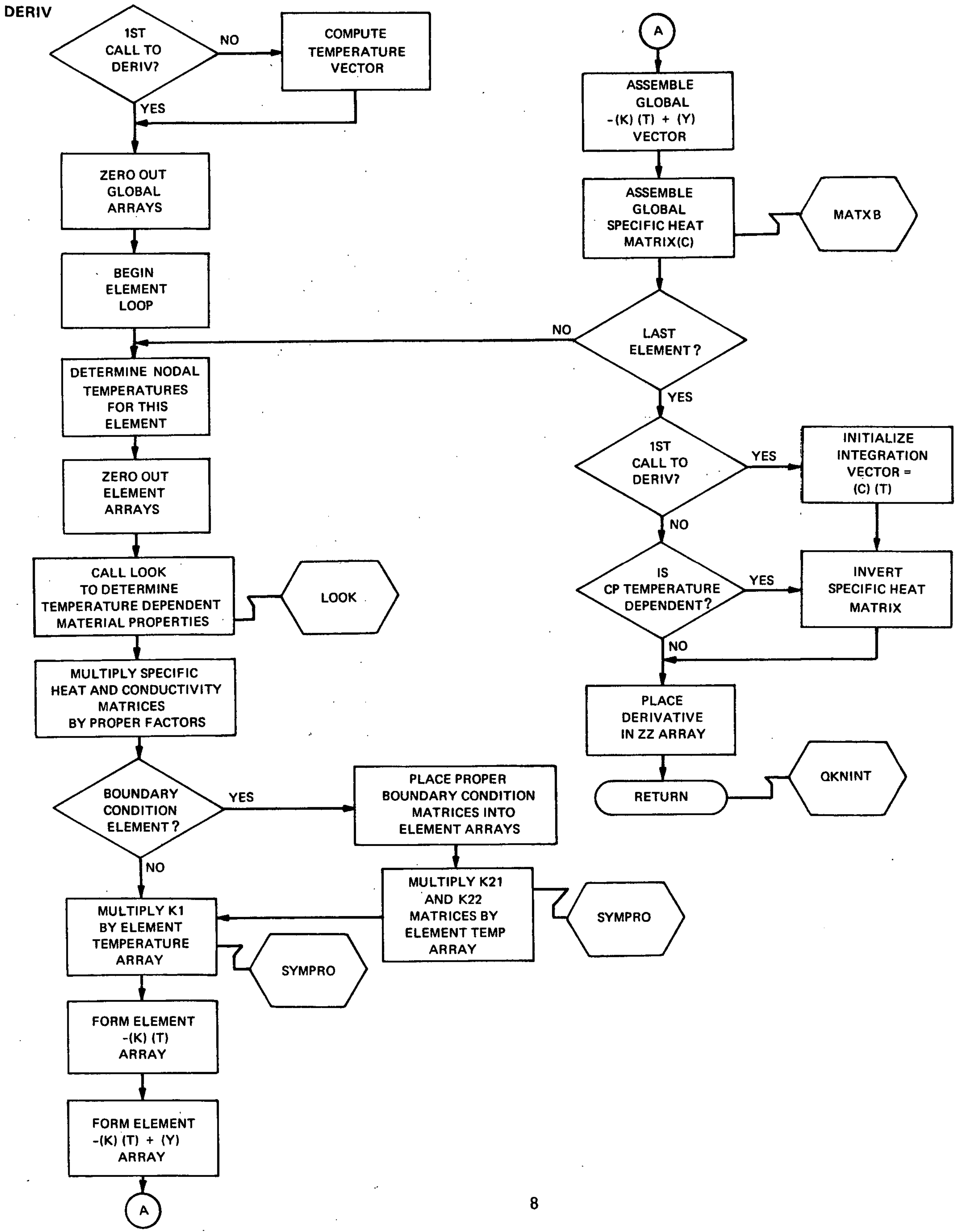
MAIN



DERIV

This routine computes and assembles the derivative of temperature which is required by the integration package to evaluate the temperature.

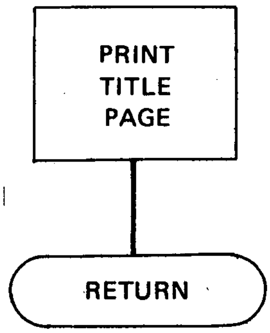
It is called from QKNINT and QKNUIN.


DERIV
1ST CALL TO DERIV?
NO
YES
COMPUTE TEMPERATURE VECTOR
ZERO OUT GLOBAL ARRAYS
BEGIN ELEMENT LOOP
DETERMINE NODAL TEMPERATURES FOR THIS ELEMENT
ZERO OUT ELEMENT ARRAYS
CALL LOOK TO DETERMINE TEMPERATURE DEPENDENT MATERIAL PROPERTIES
LOOK
MULTIPLY SPECIFIC HEAT AND CONDUCTIVITY MATRICES BY PROPER FACTORS
BOUNDARY CONDITION ELEMENT?
YES
NO
PLACE PROPER BOUNDARY CONDITION MATRICES INTO ELEMENT ARRAYS
MULTIPLY K21 AND K22 MATRICES BY ELEMENT TEMP ARRAY
SYMPRO
MULTIPLY K1 BY ELEMENT TEMPERATURE ARRAY
SYMPRO
FORM ELEMENT -(K) (T) ARRAY
FORM ELEMENT -(K) (T) + (Y) ARRAY
A
A
ASSEMBLE GLOBAL -(K) (T) + (Y) VECTOR
ASSEMBLE GLOBAL SPECIFIC HEAT MATRIX(C)
MATXB
LAST ELEMENT?
NO
YES
1ST CALL TO DERIV?
YES
NO
INITIALIZE INTEGRATION VECTOR = (C) (T)
IS CP TEMPERATURE DEPENDENT?
YES
NO
INVERT SPECIFIC HEAT MATRIX
PLACE DERIVATIVE IN ZZ ARRAY
RETURN
QKNINT

FECOM

This routine prints the title page for each case. It is called from MAIN.

FECOM

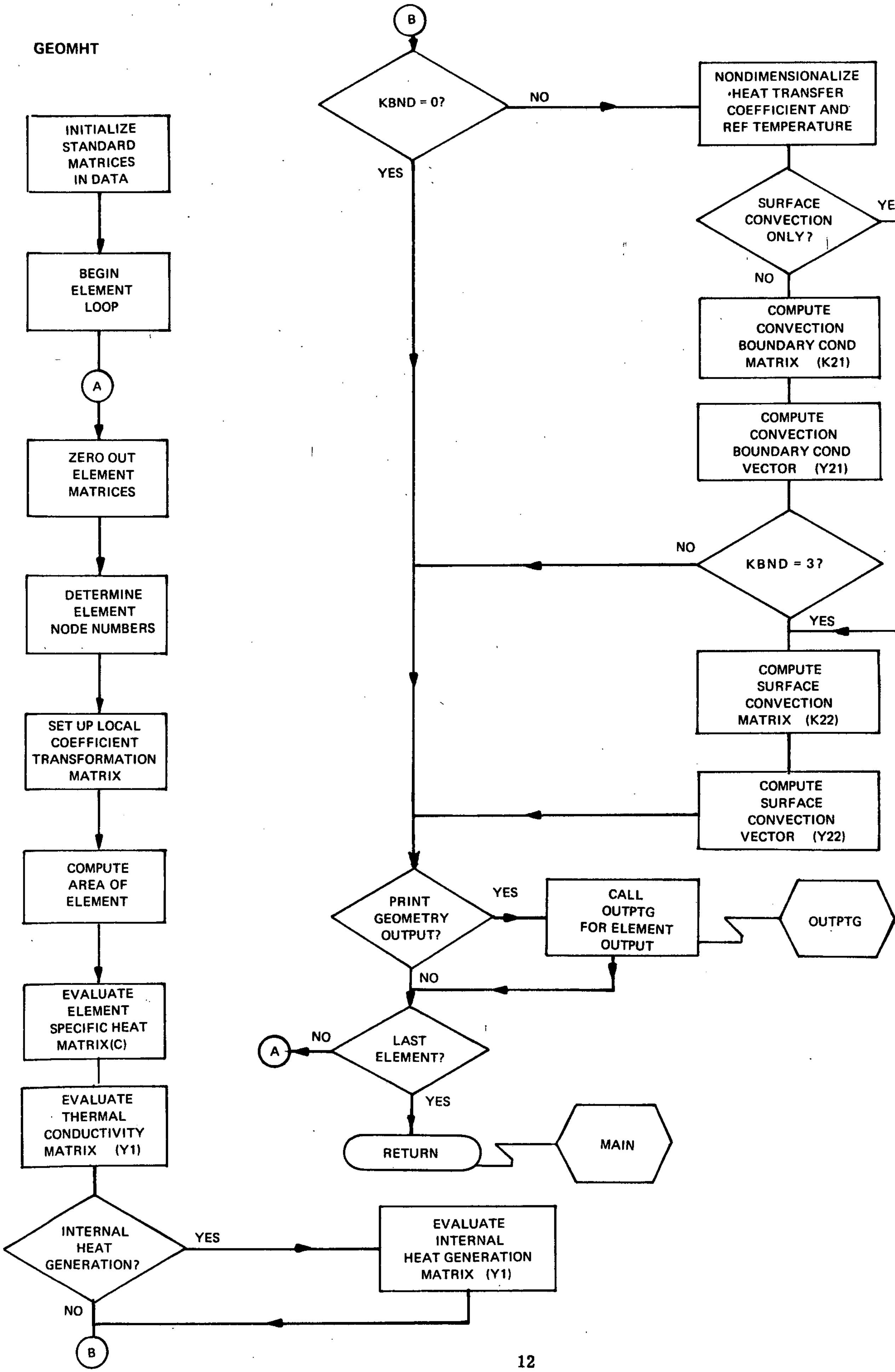


GEOMHT

This routine computes the element matrices required by DERIV to evaluate the derivative of temperature. They include the specific heat, thermal conductivity, internal heat generation and convection boundary condition matrices.

It is called from MAIN.

GEOMHT

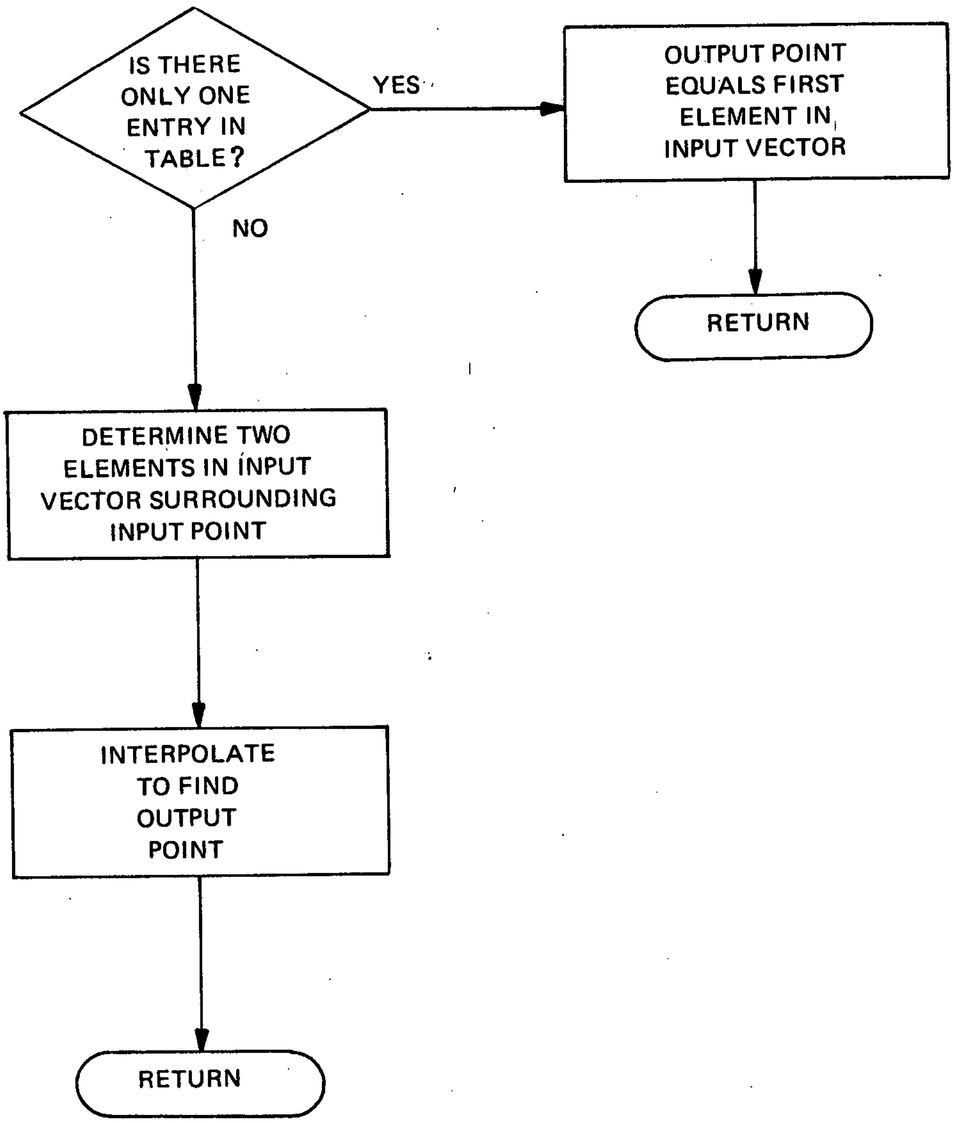

INITIALIZE STANDARD MATRICES IN DATA
BEGIN ELEMENT LOOP
A
ZERO OUT ELEMENT MATRICES
DETERMINE ELEMENT NODE NUMBERS
SET UP LOCAL COEFFICIENT TRANSFORMATION MATRIX
COMPUTE AREA OF ELEMENT
EVALUATE ELEMENT SPECIFIC HEAT MATRIX(C)
EVALUATE THERMAL CONDUCTIVITY MATRIX (Y1)
INTERNAL HEAT GENERATION?
YES
EVALUATE INTERNAL HEAT GENERATION MATRIX (Y1)
NO
B
B
KBND = 0?
NO
NONDIMENSIONALIZE HEAT TRANSFER COEFFICIENT AND REF TEMPERATURE
YES
SURFACE CONVECTION ONLY?
YES
NO
COMPUTE CONVECTION BOUNDARY COND MATRIX (K21)
COMPUTE CONVECTION BOUNDARY COND VECTOR (Y21)
NO
KBND = 3?
YES
COMPUTE SURFACE CONVECTION MATRIX (K22)
COMPUTE SURFACE CONVECTION VECTOR (Y22)
PRINT GEOMETRY OUTPUT?
YES
CALL OUTPTG FOR ELEMENT OUTPUT
OUTPTG
NO
LAST ELEMENT?
NO
A
YES
RETURN
MAIN

LOOK

This is a one-dimensional interpolation routine. It is used to determine the material property values that are temperature dependent. These properties include specific heat, thermal conductivity and density and the tables are set up as properties at a specified temperature.

It is called from MAIN and DERIV.

LOOK



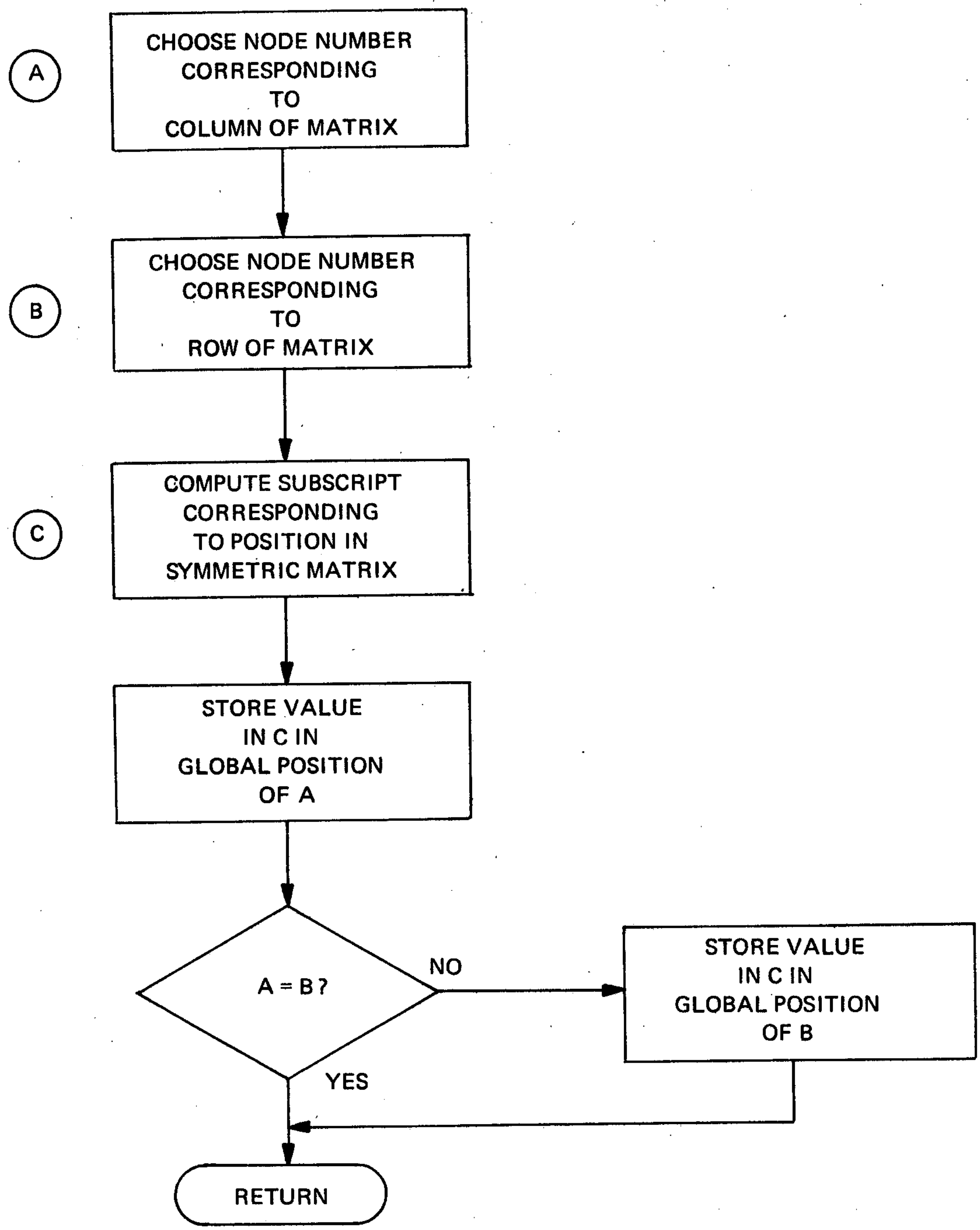
IS THERE ONLY ONE ENTRY IN TABLE?
YES
OUTPUT POINT EQUALS FIRST ELEMENT IN INPUT VECTOR
RETURN
NO
DETERMINE TWO ELEMENTS IN INPUT VECTOR SURROUNDING INPUT POINT
INTERPOLATE TO FIND OUTPUT POINT
RETURN

MATXB

This routine assembles the condensed global specific heat matrix from element specific heat matrices.

It is called from DERIV.

MATXB



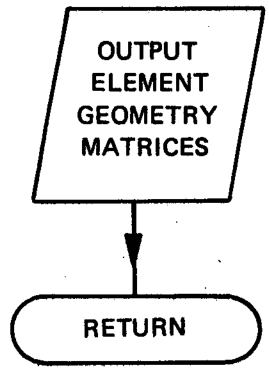
A
CHOOSE NODE NUMBER CORRESPONDING TO COLUMN OF MATRIX
B
CHOOSE NODE NUMBER CORRESPONDING TO ROW OF MATRIX
C
COMPUTE SUBSCRIPT CORRESPONDING TO POSITION IN SYMMETRIC MATRIX
STORE VALUE IN C IN GLOBAL POSITION OF A
A = B ?
NO
STORE VALUE IN C IN GLOBAL POSITION OF B
YES
RETURN

OUTPTG

This is the routine for the optional geometry output. It is called if the user inputs KODG equal to 1.

It is called from GEOMHT.

OUTPTG



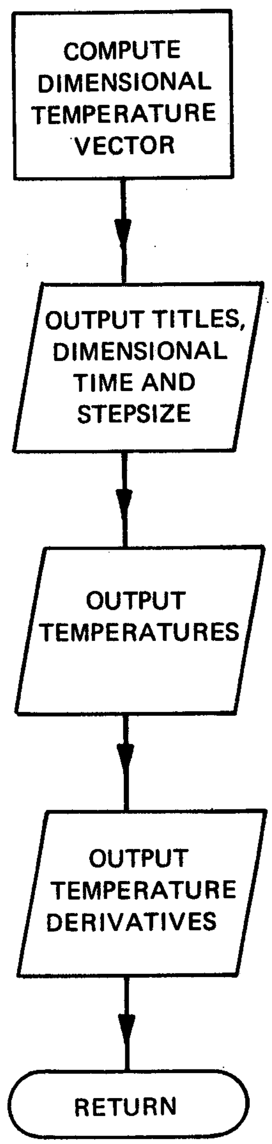
OUTPUT

This standard routine outputs temperature, derivative of temperature, and other parameters at requested intervals.

The standard routine outputs computed values in tabular form. If the user wishes, he can readily design an output routine conforming to the geometry of the problem (as illustrated for the sample problem). This is done using the variables NROWS, NCOLS and IOUT.

OUTPUT is called from QKNINT.

OUTPUT

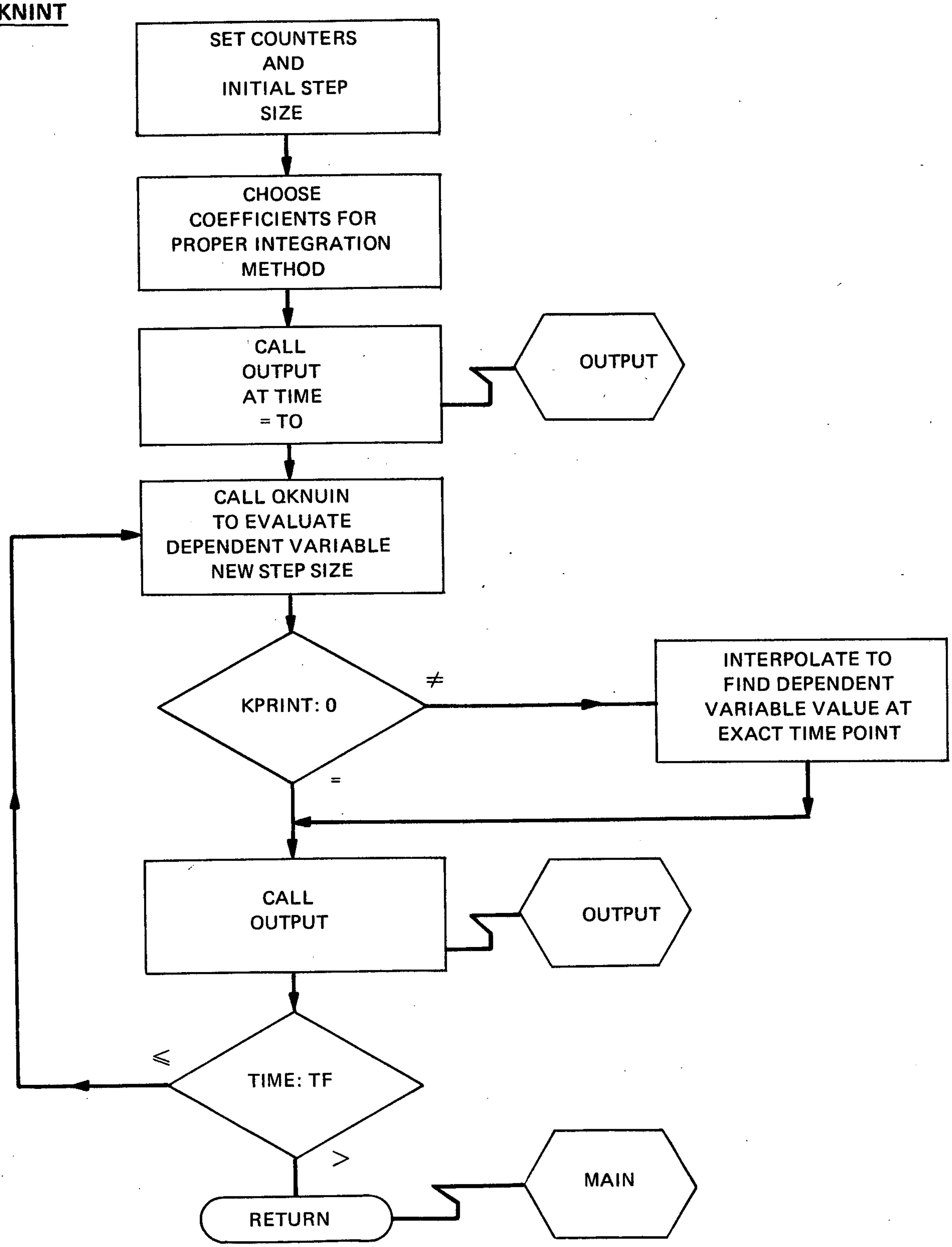

COMPUTE DIMENSIONAL TEMPERATURE VECTOR
OUTPUT TITLES, DIMENSIONAL TIME AND STEPSIZE
OUTPUT TEMPERATURES
OUTPUT TEMPERATURE DERIVATIVES
RETURN

QKNINT

This routine numerically integrates the system of ordinary differential equations written on nodal temperatures. It employs one of two predictor-corrector, integration algorithms. Both are three-stage, one-step, first order accurate explicit numerical integration procedures.

It is called from MAIN.

QKNINT

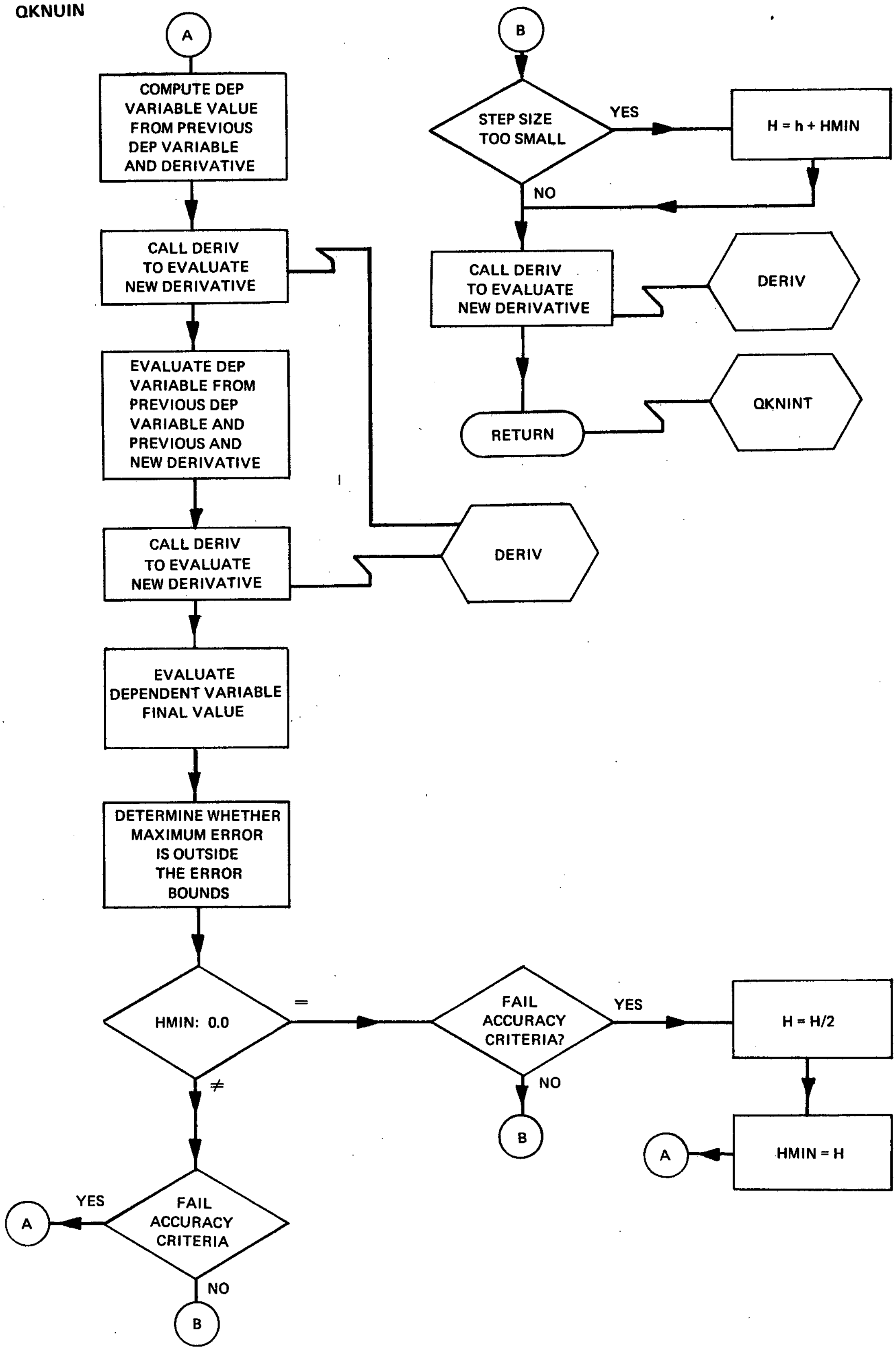

SET COUNTERS AND INITIAL STEP SIZE
CHOOSE COEFFICIENTS FOR PROPER INTEGRATION METHOD
CALL OUTPUT AT TIME = TO
OUTPUT
CALL QKNUIN TO EVALUATE DEPENDENT VARIABLE NEW STEP SIZE
KPRINT: 0
≠
=
INTERPOLATE TO FIND DEPENDENT VARIABLE VALUE AT EXACT TIME POINT
CALL OUTPUT
OUTPUT
TIME: TF
≤
>
RETURN
MAIN

QKNUIN

This routine computes the new values of temperature. It performs an accuracy comparison, and may increase, decrease, or keep constant the step size for the next integration step.

It is called from QKNINT.

QKNUIN



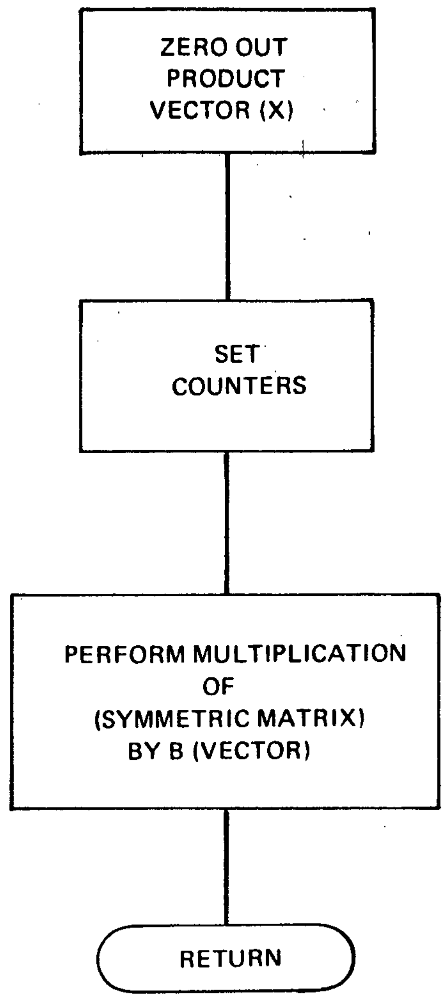
A
COMPUTE DEP VARIABLE VALUE FROM PREVIOUS DEP VARIABLE AND DERIVATIVE
CALL DERIV TO EVALUATE NEW DERIVATIVE
EVALUATE DEP VARIABLE FROM PREVIOUS DEP VARIABLE AND PREVIOUS AND NEW DERIVATIVE
CALL DERIV TO EVALUATE NEW DERIVATIVE
DERIV
EVALUATE DEPENDENT VARIABLE FINAL VALUE
DETERMINE WHETHER MAXIMUM ERROR IS OUTSIDE THE ERROR BOUNDS
HMIN: 0.0
=
≠
FAIL ACCURACY CRITERIA
YES
A
NO
B
FAIL ACCURACY CRITERIA?
YES
H = H/2
HMIN = H
A
NO
B
B
STEP SIZE TOO SMALL
YES
H = h + HMIN
NO
CALL DERIV TO EVALUATE NEW DERIVATIVE
DERIV
RETURN
QKNINT

SYMPRO

This routine multiplies a symmetric matrix by a vector.

It is called from DERIV.

SYMPRO


ZERO OUT PRODUCT VECTOR (X)
SET COUNTERS
PERFORM MULTIPLICATION OF (SYMMETRIC MATRIX) BY B (VECTOR)
RETURN

III. INPUT FORMAT

The following section illustrates the proper format and sequence for all input data.

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COMPUTER INPUT FORM

COMOC – THERMAL ANALYSIS VARIANT

☐ RUN
☐ HOLD

CUSTOMER NASA/GSFC EXT.

PROGRAM	PROBLEM	ANALYST	PERMANENT NO.	DEPT.	W.O.	C.C.	DATE	IDENT NO.

1) CARD TYPE A - FORMAT (I5)

NOCSS - NUMBER OF CASES

2) CARD TYPE A - FORMAT (I5)

NTITLE - NUMBER OF TITLE CARDS FOR THIS CASE
MUST HAVE AT LEAST ONE TITLE CARD, MAXIMUM OF 6

3) CARD TYPE B - FORMAT (18A4)

((HEAD (I,J), J=1, 18), I=1,NTITLE)

HEAD - TITLE CARD
THERE SHOULD BE NTITLE CARDS OF TYPE B.

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COMPUTER INPUT FORM

COMOC – THERMAL ANALYSIS VARIANT

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CUSTOMER NASA/GSFC EXT. ______ Page 2 of 7

PROGRAM	PROBLEM	ANALYST	PERMANENT NO.	DEPT.	W.O.	C.C.	DATE	IDENT NO.
1–7	10–14	18–20	24–29	32–35	38–41	43–45	47–52	73–80

4) CARD TYPE C – FORMAT 5I4,3I2 – GENERAL INFORMATION CARD

- NOUTP = 0, IF STANDARD TABULAR OUTPUT IS DESIRED.
  - ≠ 0, IF USER SUPPLIED OUTPUT ROUTINE IS USED.
- LIMPT = TOTAL NUMBER OF DERIV ROUTINE OUTPUTS DESIRED.
- KODG = 0, IF GEOMETRY OUTPUT IS NOT DESIRED
  - ≠ 0, IF GEOMETRY OUTPUT IS DESIRED
- NCOORD = 2, PLANE TRIANGULAR ELEMENTS
  - = 3, AXISYMETRIC, TRIANGULAR RING ELEMENTS
- NTAB = NUMBER OF TEMPERATURE DEPENDENT PROPERTY LEVELS
- NMAT = NUMBER OF MATERIALS
- NELEM = NUMBER OF ELEMENTS
- NNODE = NUMBER OF NODES

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COMPUTER INPUT FORM

COMOC – THERMAL ANALYSIS VARIANT

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PROGRAM | PROBLEM | ANALYST | PERMANENT NO. | DEPT. | W.O. | C.C. | DATE | IDENT NO.

5) CARD TYPE D - ELEMENT INFORMATION CARD

FORMAT (4I4,4X,I4,F8.2,4X,I4,4F8.2)

THERE SHOULD BE NELEM CARDS OF TYPE D

A	B*	C*	D*	----	E	F	----	G	H	I	J	K

A) - IELEM - ELEMENT NUMBER

B) - 1ST NODE OF ELEMENT

C) - 2ND NODE OF ELEMENT

D) - 3RD NODE OF ELEMENT

E) - NELEM - ELEMENT MATERIAL NUMBER

F) - TK - ELEMENT THICKNESS

G) - KBND - BOUNDARY CONDITION CODE (0 - NO BOUNDARY CONDITION, 1 - BOUNDARY CONVECTION, 2 - SURFACE CONVECTION, **3 - BOUNDARY & SURFACE CONVECTION

H) - Q - INTERNAL HEAT GENERATION VALUE

I) - HC - CONVECTIVE HEAT TRANSFER COEFFICIENT

J) - TR - AMBIENT FLUID TEMPERATURE

K) - F - VALUE OF NORMAL FLUX

NOTES

* - NODES A, B AND C SHOULD BE DESCRIBED IN A COUNTERCLOCKWISE DIRECTION
IF THIS IS A BOUNDARY ELEMENT, NODES A AND B SHOULD BE THE BOUNDARY NODES

** - WHEN BOTH CONVECTIVE BOUNDARY CONDITIONS ARE SPECIFIED, THEY MUST BOTH HAVE THE SAME HEAT TRANSFER COEFFICIENTS AND AMBIENT TEMPERATURES.

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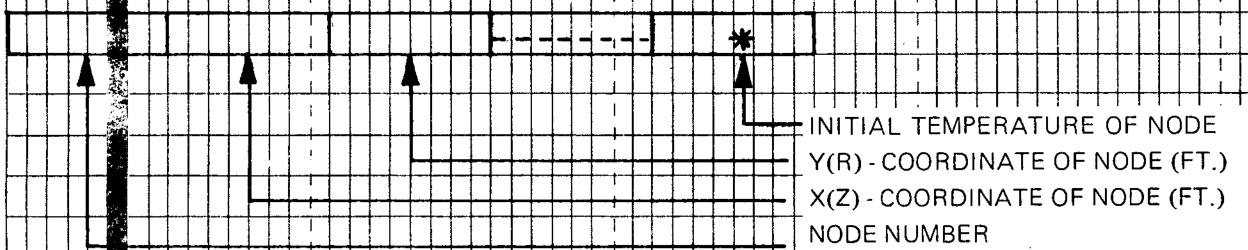
PROGRAM | PROBLEM | ANALYST | PERMANENT NO. | DEPT. | W.O. | C.C. | DATE | IDENT NO.

6) CARD TYPE E – NODAL INFORMATION CARD

FORMAT (I8,2E8.2, 8X,E8.2)

THERE SHOULD BE ___ NODE CARDS OF TYPE E



*NOTE – IF THE TEMPERATURE OF THIS NODE IS FIXED, PRECEDE THE TEMPERATURE VALUE BY A NEGATIVE SIGN (-)

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PROGRAM	PROBLEM	ANALYST	PERMANENT NO.	DEPT.	W.O.	C.C.	DATE	IDENT NO.

7) CARD TYPE F - MATERIAL IDENTIFICATION

FORMAT (I8,2E8.2,8X,3E8.2)

A	B	C	XXXXXXXX	D	E	F

A) - MATERIAL NUMBER

B) - CONDUCTIVITY COEF., KX, (BTU/HR FT °R)

C) - CONDUCTIVITY COEF., KY

D) - SPECIFIC HEAT, CP, (BTU/LBM °R)

E) - DENSITY, ρ (LBM/FT^3)

F) - REFERENCE TEMPERATURE (R)

NOTE: NTAB REFERENCE LEVELS ARE REQUIRED FOR EVERY MATERIAL

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PROGRAM | PROBLEM | ANALYST | PERMANENT NO. | DEPT. | W.O. | C.C. | DATE | IDENT NO.

8) CARD TYPE G - INTEGRATION INFORMATION CARD.

FORMAT (2I5,5F10.7)

A	B	C	D	E	F	G

A) - KPRINT = 1-INTERPOLATE TO GET OUTPUT AT EXACT INTERVALS OF DELP.
0-OUTPUT NOT CONSTRAINED TO DELP.

B) - KEYMTD - INTEGRATION METHOD.

C) - EPS - ACCURACY CRITERIA.

D) - HMIN - MINIMUM STEP SIZE.

E) - TF - FINAL TIME.

F) - TO - INITIAL TIME.

G) - DELP - PRINT INTERVAL.

NOTE - IF STANDARD OUTPUT ROUTINE IS USED, THIS IS THE END OF THE INPUT FOR THIS CASE.

IF THERE ARE FURTHER CASES RETURN TO CARD NO. 2 AND BEGIN INPUT FOR THE NEXT CASE.

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COMOC – THERMAL ANALYSIS VARIANT

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HOLD

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PROGRAM PROBLEM ANALYST PERMANENT NO. DEPT. W.O. C.C. DATE IDENT NO.

NOTE THE FOLLOWING CARDS ARE TO BE INPUT ONLY IF THERE EXISTS A
USER SUPPLIED OUTPUT ROUTINE.
IF THIS IS THE CASE NOUTP ON CARD NO. 4 SHOULD BE SET EQUAL TO ONE.

9) CARD TYPE A - FORMAT(I5)

NROWS - NUMBER OF ROWS OF OUTPUT NODES.

THE NEXT SET OF CARDS ARE TO BE INPUT IN GROUPS OF TWO FOR EACH ROW.

10) CARD TYPE A - FORMAT(I5)

NCOLS - NUMBER OF NODES FOR THE PARTICULAR ROW.

11) CARD TYPE F - FORMAT(16I5)

IOUT - NODE NUMBERS TO BE OUTPUT FOR THE PARTICULAR ROW.

THIS IS THE END OF THE INPUT
IF THERE IS MORE THAN ONE CASE, RETURN TO CARD NO. 2 AND BEGIN THE INPUT FOR THE NEXT CASE.

IV. INPUT FOR SAMPLE PROBLEM

This section describes the input required to generate a ten second firing of a 104 finite element discretization of a small axisymmetric, thrust-vector-control rocket motor as illustrated on the following page. The technical aspects of this test are fully discussed in Bell Aerospace Report 9500-920 257. Section V illustrates and provides a complete description of the output from COMOC using the input detailed in this section. Section VI contains the listing of the user-written output subroutine used for output display of this problem.

The input is illustrated on computer forms. Where numerous cards of the same format are required (such as the element information cards), only two such cards are shown. The input is completely printed out at the beginning of output for any run by COMOC. The user should refer to Section III for a full description of all element and node dependent input.

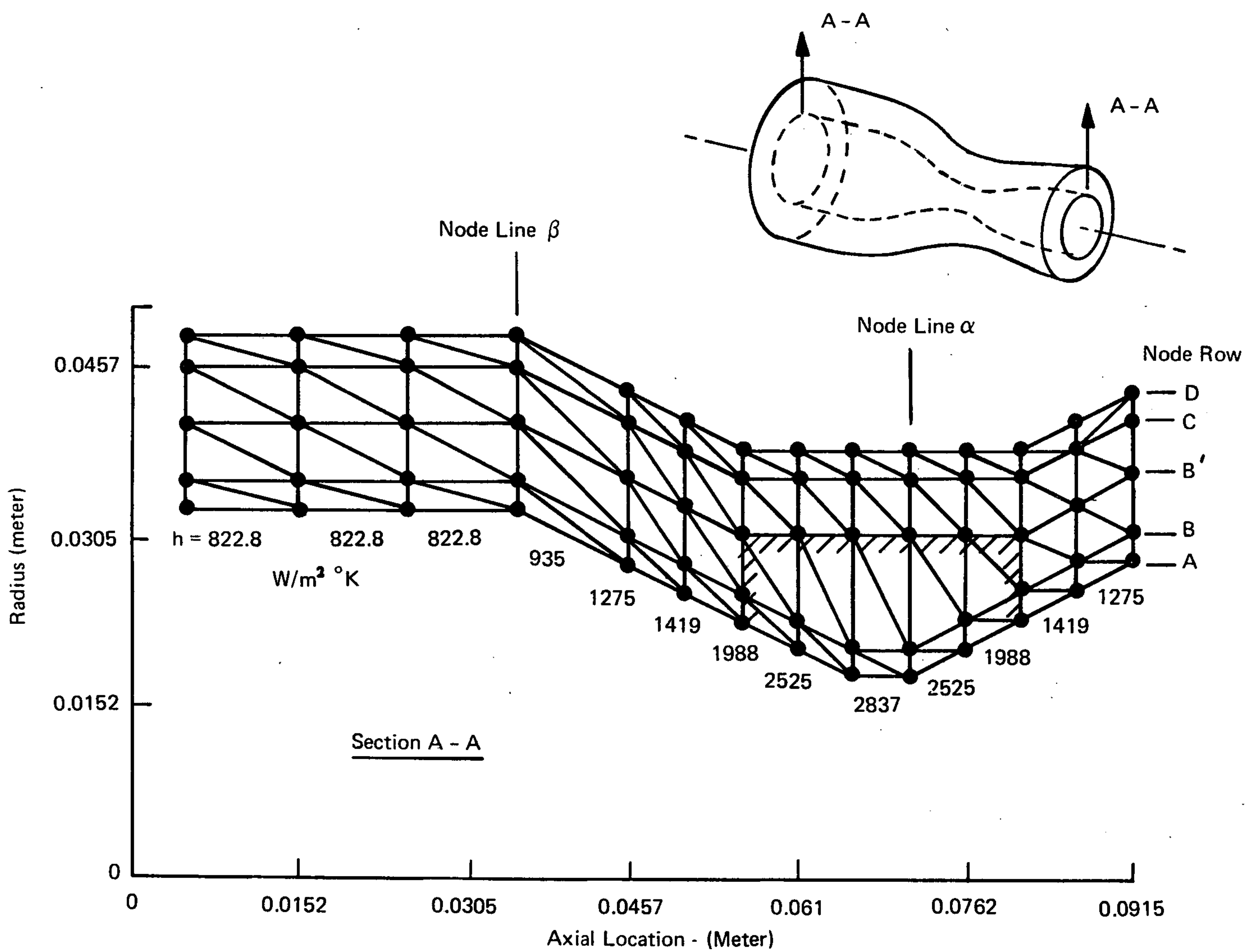

Figure 1. Finite Element Discretization of Thrust Vector Control Rocket Motor

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COMPUTER INPUT FORM

COMOC – THERMAL ANALYSIS VARIANT

☐ RUN
☐ HOLD

Page ______ of ______

CUSTOMER ______ EXT. ______

PROGRAM | PROBLEM | ANALYST | PERMANENT NO. | DEPT. | W.O. | C.C. | DATE | IDENT NO.

```
1)     1
2)     6
3)               STANDARD TEST CASE FOR COMOC
4) 104 FINITE ELEMENT DISCRETIZATION OF A SMALL THRUST VECTOR CONTROL
5) ROCKET MOTOR, USING TRIANGULAR AXISYMMETRIC RING ELEMENTS WITH VARIABLE
6) CONVECTION BOUNDARY CONDITIONS APPLIED TO INTERIOR SURFACE. TRANSIENT
7) BEHAVIOR DURING A 1Ø SECOND FIRING DETERMINED USING TEMPERATURE
8) DEPENDENT MATERIAL PROPERTIES AND  QKINT AUTOMATIC INTEGRATOR.
9)    70  04   1   3   3 1 1 1
10)    1   1   2  15     1  1.0             145.0     6460.0
    THRU
11)  104  27  14  28     1  1.0
```

BAC 0949 REV. 2/67

COMPUTER INPUT FORM

COMOC – THERMAL ANALYSIS VARIANT

☐ RUN
☐ HOLD

CUSTOMER NASA/GSFC EXT. ______ Page ______ of ______

PROGRAM	PROBLEM	ANALYST	PERMANENT NO.	DEPT.	W.O.	C.C.	DATE	IDENT NO.
1–7	10–14	18–20	24–29	32–35	38–41	43–45	47–52	73–80

Card	Cols 1–6	Cols 7–16	Cols 17–31	Cols 32–46	Cols 47–61
12)		1 0.2	1.3	530.	
(THRU)					
13)		70 3.6	1.7	530.	
14)		1 8.33	8.33	0.1092 506.3	460.
15)		1 16.67	16.67	0.13 506.3	1960.
16)		1 28.0	28.0	0.16 506.3	4000.
17)	0	1 0.001	0.0	0.0028 0.0	0.00028
18)	13				
19)	4				
20)	57	58 59	60		
(THRU)					
21)	2				
22)	9	10			

V. OUTPUT DISPLAY AND DESCRIPTION FOR SAMPLE PROBLEM

This section presents sample output from the rocket motor problem described in Section IV. A description of each portion of the output is also included.

The first page of output is the general COMOC title page with the user supplied title describing the problem for which the run was made and the date. This is followed by pages containing a complete reproduction of input data. Included are titles, general information, element information, nodal information and material properties tables. This is followed by integration control parameter information and the non-dimensionalizing constants computed in the MAIN routine.

The following pages illustrate this information for the sample problem.

C C M C C

COMPUTATIONAL CONTINUUM MECHANICS
THERMAL ANALYSIS VARIANT

STANDARD TEST CASE FOR CCMCC

104 FINITE ELEMENT DISCRETIZATION OF A SMALL THRUST VECTOR CONTROL ROCKET MOTOR, USING TRIANGULAR AXISYMMETRIC RING ELEMENTS WITH VARIABLE CONVECTIVE BOUNDARY CONDITIONS APPLIED TO INTERIOR SURFACE. TRANSIENT BEHAVIOR DURING A 10 SECOND FIRING DETERMINED USING TEMPERATURE DEPENDENT MATERIAL PROPERTIES AND GKNINT AUTOMATIC INTEGRATOR.

10/26/72

ELEMENT DATA

NUMBER OF ELEMENTS = 104
NUMBER OF NODES = 70
NUMBER OF MATERIALS= 1

ELEMENT	NODES			MATERIAL	HEAT TRANSFER COEF.	REFERENCE TEMP.	INTERNAL H.G.	NORMAL FLUX	THICKNESS
1	1	2	15	1	0.14500E 03	0.64600E 04	0.0	0.0	0.10000E 01
2	15	2	16	1	0.0	0.0	0.0	0.0	0.10000E 01
3	2	3	16	1	0.14500E 03	0.64600E 04	0.0	0.0	0.10000E 01
4	16	3	17	1	0.0	0.0	0.0	0.0	0.10000E 01
5	3	4	17	1	0.14500E 03	0.64600E 04	0.0	0.0	0.10000E 01
6	17	4	18	1	0.0	0.0	0.0	0.0	0.10000E 01
7	4	5	18	1	0.16500E 03	0.64600E 04	0.0	0.0	0.10000E 01
8	18	5	19	1	0.0	0.0	0.0	0.0	0.10000E 01
9	5	6	19	1	0.22500E 03	0.64600E 04	0.0	0.0	0.10000E 01
10	19	6	20	1	0.0	0.0	0.0	0.0	0.10000E 01
11	6	7	20	1	0.25000E 03	0.64600E 04	0.0	0.0	0.10000E 01
12	20	7	21	1	0.0	0.0	0.0	0.0	0.10000E 01
13	7	8	21	1	0.35000E 03	0.64600E 04	0.0	0.0	0.10000E 01
14	21	8	22	1	0.0	0.0	0.0	0.0	0.10000E 01
15	8	9	22	1	0.44500E 03	0.64600E 04	0.0	0.0	0.10000E 01
16	22	9	23	1	0.0	0.0	0.0	0.0	0.10000E 01
17	9	10	23	1	0.50000E 03	0.64600E 04	0.0	0.0	0.10000E 01
18	23	10	24	1	0.0	0.0	0.0	0.0	0.10000E 01
19	10	11	24	1	0.44500E 03	0.64600E 04	0.0	0.0	0.10000E 01
20	24	11	25	1	0.0	0.0	0.0	0.0	0.10000E 01
21	11	12	25	1	0.35000E 03	0.64600E 04	0.0	0.0	0.10000E 01
22	25	12	26	1	0.0	0.0	0.0	0.0	0.10000E 01
23	12	13	26	1	0.25000E 03	0.64600E 04	0.0	0.0	0.10000E 01
24	26	13	27	1	0.0	0.0	0.0	0.0	0.10000E 01
25	13	14	27	1	0.22500E 03	0.64600E 04	0.0	0.0	0.10000E 01
26	15	16	29	1	0.0	0.0	0.0	0.0	0.10000E 01
27	29	16	30	1	0.0	0.0	0.0	0.0	0.10000E 01
28	16	17	30	1	0.0	0.0	0.0	0.0	0.10000E 01
29	30	17	31	1	0.0	0.0	0.0	0.0	0.10000E 01
30	17	18	31	1	0.0	0.0	0.0	0.0	0.10000E 01
31	31	18	32	1	0.0	0.0	0.0	0.0	0.10000E 01
32	18	19	32	1	0.0	0.0	0.0	0.0	0.10000E 01
33	32	19	33	1	0.0	0.0	0.0	0.0	0.10000E 01
34	19	20	33	1	0.0	0.0	0.0	0.0	0.10000E 01
35	33	20	34	1	0.0	0.0	0.0	0.0	0.10000E 01
36	20	21	34	1	0.0	0.0	0.0	0.0	0.10000E 01
37	34	21	35	1	0.0	0.0	0.0	0.0	0.10000E 01
38	21	22	35	1	0.0	0.0	0.0	0.0	0.10000E 01
39	35	22	36	1	0.0	0.0	0.0	0.0	0.10000E 01
40	22	23	36	1	0.0	0.0	0.0	0.0	0.10000E 01
41	36	23	37	1	0.0	0.0	0.0	0.0	0.10000E 01
42	23	24	37	1	0.0	0.0	0.0	0.0	0.10000E 01
43	37	24	38	1	0.0	0.0	0.0	0.0	0.10000E 01
44	24	25	38	1	0.0	0.0	0.0	0.0	0.10000E 01
45	38	25	39	1	0.0	0.0	0.0	0.0	0.10000E 01
46	25	26	39	1	0.0	0.0	0.0	0.0	0.10000E 01
47	39	26	40	1	0.0	0.0	0.0	0.0	0.10000E 01

48	26	27	40	1	C.C	0.0	0.0	0.0	C.10000E 01
49	40	27	41	1	C.0	0.0	0.0	0.0	C.10000E 01
50	27	28	41	1	C.C	0.0	0.0	0.0	C.10000E 01
51	41	28	42	1	C.0	0.0	0.0	0.0	C.100C0E 01
52	29	30	43	1	C.0	0.0	0.0	0.0	C.100C0E 01
53	43	30	44	1	C.C	0.0	0.0	0.0	C.100C0E 01
54	30	31	44	1	0.0	0.0	0.0	0.0	0.100C0E 01
55	44	31	45	1	C.0	0.0	0.0	0.0	C.10000E 01
56	31	32	45	1	0.0	0.0	0.0	0.0	C.100C0E 01
57	45	32	46	1	C.C	0.0	0.0	0.0	0.100C0E 01
58	32	33	46	1	0.0	0.0	0.0	0.0	C.10000E 01
59	46	33	47	1	C.0	0.0	0.0	0.0	0.10000E 01
60	33	34	47	1	C.C	0.0	0.0	0.0	0.100C0E 01
61	47	34	48	1	C.0	0.0	0.0	0.0	C.100C0E 01
62	34	35	48	1	0.0	0.0	0.0	0.0	C.10000E 01
63	48	35	49	1	C.0	0.0	0.0	0.0	0.10000E 01
64	35	36	49	1	C.0	0.0	0.0	0.0	C.10000E 01
65	49	36	50	1	C.0	0.0	0.0	0.0	C.100C0E 01
66	36	37	50	1	C.0	0.0	0.0	0.0	C.100C0E 01
67	50	37	51	1	0.0	0.0	0.0	0.0	0.10000E 01
68	37	38	51	1	C.C	0.0	0.0	0.0	C.10000E 01
69	51	38	52	1	C.0	0.0	0.0	0.0	0.10000E 01
70	38	39	52	1	C.C	0.0	0.0	0.0	C.10000E 01
71	52	39	53	1	C.0	0.0	0.0	0.0	0.10000E 01
72	39	40	53	1	C.C	0.0	0.0	0.0	0.100C0E 01
73	53	40	54	1	0.C	0.0	0.0	0.0	C.100C0E 01
74	40	41	54	1	0.0	0.0	0.0	0.0	C.100C0E 01
75	54	41	55	1	C.0	0.0	0.0	0.0	C.10000E 01
76	41	42	55	1	C.0	0.0	0.0	0.0	0.100C0E 01
77	55	42	56	1	C.0	0.0	0.0	0.0	C.10000E 01
78	43	44	57	1	C.0	0.0	0.0	0.0	C.10000E 01
79	57	44	58	1	C.C	0.0	0.0	0.0	0.10000E 01
80	44	45	58	1	C.0	0.0	0.0	0.0	0.10000E 01
81	58	45	59	1	0.0	0.0	0.0	0.0	C.10000E 01
82	45	46	59	1	C.0	0.0	0.0	0.0	0.10000E 01
83	59	46	60	1	C.0	0.0	0.0	0.0	0.10000E 01
84	46	47	60	1	0.C	0.0	0.0	0.0	0.100C0E 01
85	60	47	61	1	C.0	0.0	0.0	0.0	C.10000E 01
86	47	48	61	1	C.0	0.0	0.0	0.0	0.10000E 01
87	61	48	62	1	C.0	0.0	0.0	0.0	0.100C0E 01
88	48	49	62	1	C.0	0.0	0.0	0.0	C.10000E 01
89	62	49	63	1	C.C	0.0	0.0	0.0	C.100C0E 01
90	49	50	63	1	C.C	0.0	0.0	0.0	C.100C0E 01
91	63	50	64	1	C.C	0.0	0.0	0.0	C.100C0E 01
92	50	51	64	1	C.0	0.0	0.0	0.0	C.100C0E 01
93	64	51	65	1	C.C	0.0	0.0	0.0	C.100C0E 01
94	51	52	65	1	C.0	0.0	0.0	0.0	C.100C0E 01
95	65	52	66	1	C.0	0.0	0.0	0.0	C.100C0E 01
96	52	53	66	1	C.0	0.0	0.0	0.0	C.100C0E 01
97	66	53	67	1	C.C	0.0	0.0	0.0	0.100C0E 01
98	53	54	67	1	C.0	0.0	0.0	0.0	0.100C0E 01
99	67	54	68	1	C.0	0.0	0.0	0.0	0.10000E 01
100	54	55	68	1	C.0	0.0	0.0	0.0	0.10000E 01
101	68	55	69	1	C.0	0.0	0.0	0.0	C.100C0E 01
102	55	70	69	1	C.0	0.0	0.0	0.0	C.100C0E 01
103	55	56	70	1	C.C	0.0	0.0	0.0	C.100C0E 01
104	27	14	28	1	C.0	0.0	0.0	0.0	C.100C0E 01

NODAL DATA

AXISYMMETRIC PROBLEM

NODE	Z(FT.)	R(FT.)	INITIAL TEMP(F)
1	0.16670000E-01	0.10832995E 00	0.53000000E 03
2	0.49999997E-01	0.10832995E 00	0.53000000E 03
3	0.83329976E-01	0.10832995E 00	0.53000000E 03
4	0.11666995E 00	0.10832995E 00	0.53000000E 03
5	0.14999998E 00	0.91669977E-01	0.53000000E 03
6	0.16666996E 00	0.83329976E-01	0.53000000E 03
7	0.18333000E 00	0.74999988E-01	0.53000000E 03
8	0.19999999E 00	0.66669941E-01	0.53000000E 03
9	0.21666998E 00	0.58329999E-01	0.53000000E 03
10	0.23332995E 00	0.58329999E-01	0.53000000E 03
11	0.25000000E 00	0.66669941E-01	0.53000000E 03
12	0.26666999E 00	0.74999988E-01	0.53000000E 03
13	0.28332996E 00	0.83329976E-01	0.53000000E 03
14	0.29999995E 00	0.91669977E-01	0.53000000E 03
15	0.16670000E-01	0.11666995E 00	0.53000000E 03
16	0.49999997E-01	0.11666995E 00	0.53000000E 03
17	0.83329976E-01	0.11666995E 00	0.53000000E 03
18	0.11666995E 00	0.11666995E 00	0.53000000E 03
19	0.14999998E 00	0.99999964E-01	0.53000000E 03
20	0.16666996E 00	0.91669977E-01	0.53000000E 03
21	0.18333000E 00	0.83329976E-01	0.53000000E 03
22	0.19999999E 00	0.74999988E-01	0.53000000E 03
23	0.21666998E 00	0.66669941E-01	0.53000000E 03
24	0.23332995E 00	0.66669941E-01	0.53000000E 03
25	0.25000000E 00	0.74999988E-01	0.53000000E 03
26	0.26666999E 00	0.83329976E-01	0.53000000E 03
27	0.28332996E 00	0.91669977E-01	0.53000000E 03
28	0.29999995E 00	0.99999964E-01	0.53000000E 03
29	0.16670000E-01	0.13332999E 00	0.53000000E 03
30	0.49999997E-01	0.13332999E 00	0.53000000E 03
31	0.83329976E-01	0.13332999E 00	0.53000000E 03
32	0.11666995E 00	0.13332999E 00	0.53000000E 03
33	0.14999998E 00	0.11666995E 00	0.53000000E 03
34	0.16666996E 00	0.10832995E 00	0.53000000E 03
35	0.18333000E 00	0.99999964E-01	0.53000000E 03
36	0.19999999E 00	0.99999964E-01	0.53000000E 03
37	0.21666998E 00	0.99999964E-01	0.53000000E 03
38	0.23332995E 00	0.99999964E-01	0.53000000E 03
39	0.25000000E 00	0.99999964E-01	0.53000000E 03
40	0.26666999E 00	0.99999964E-01	0.53000000E 03
41	0.28332996E 00	0.10832995E 00	0.53000000E 03
42	0.29999995E 00	0.11666995E 00	0.53000000E 03
43	0.16670000E-01	0.14999998E 00	0.53000000E 03
44	0.49999997E-01	0.14999998E 00	0.53000000E 03
45	0.83329976E-01	0.14999998E 00	0.53000000E 03
46	0.11666995E 00	0.14999998E 00	0.53000000E 03

47	0.14999998E 00	0.13332999E 00	0.53000000E 03
48	0.16666996E 00	0.12500000E 00	0.53000000E 03
49	0.18333000E 00	0.11666995E 00	0.53000000E 03
50	0.19999999E 00	0.11666995E 00	0.53000000E 03
51	0.21666998E 00	0.11666995E 00	0.53000000E 03
52	0.23332995E 00	0.11666995E 00	0.53000000E 03
53	0.25000000E 00	0.11666995E 00	0.53000000E 03
54	0.26666999E 00	0.11666995E 00	0.53000000E 03
55	0.28332996E 00	0.12500000E 00	0.53000000E 03
56	0.29999995E 00	0.13332999E 00	0.53000000E 03
57	0.16670000E-01	0.15832996E 00	0.53000000E 03
58	0.49999997E-01	0.15832996E 00	0.53000000E 03
59	0.83329976E-01	0.15832996E 00	0.53000000E 03
60	0.11666995E 00	0.15832996E 00	0.53000000E 03
61	0.14999998E 00	0.14166999E 00	0.53000000E 03
62	0.16666996E 00	0.13332999E 00	0.53000000E 03
63	0.18333000E 00	0.12500000E 00	0.53000000E 03
64	0.19999999E 00	0.12500000E 00	0.53000000E 03
65	0.21666998E 00	0.12500000E 00	0.53000000E 03
66	0.23332995E 00	0.12500000E 00	0.53000000E 03
67	0.25000000E 00	0.12500000E 00	0.53000000E 03
68	0.26666999E 00	0.12500000E 00	0.53000000E 03
69	0.28332996E 00	0.13332999E 00	0.53000000E 03
70	0.29999995E 00	0.14166999E 00	0.53000000E 03

MATERIAL PROPERTIES

MATERIAL NUMBER	CONDUCTIVITY DIRECTION 1 (BTU/FT*HR*R)	CONDUCTIVITY DIRECTION 2 (BTU/FT*HR*R)	SPECIFIC HEAT (BTU/FT**3*R)	DENSITY (LBM/FT**3)	TEMPERATURE (R)
1	0.83300E 01	0.83300E 01	0.10920E 00	0.50630E 03	0.46000E 03
1	0.16670E 02	0.16670E 02	0.13000E 00	0.50630E 03	0.19600E 04
1	0.28000E 02	0.28000E 02	0.16000E 00	0.50630E 03	0.40000E 04

NON-DIMENSIONALIZING CONSTANTS

THERMAL CONDUCTIVITY	=	28.000
LENGTH	=	0.100
REFERENCE TEMPERATURE	=	6460.000
DENSITY	=	506.300
TIME FACTOR	=	0.029
SPECIFIC HEAT	=	0.160

SPECIFIC HEAT MATRIX NON-D CONSTANT	=	0.012
THERMAL CONDUCTIVITY MATRIX NON-D CONSTANT	=	0.036

INTEGRATION INPUT

FINAL TIME(TF)	=	0.00280
TEST CRITERION(EPS)	=	0.01000
INITIAL TIME(TO)	=	0.0
NUMBER OF INTEGRATION NODES	=	70
KEY-METHOD(KEYMTD)	=	1
MINIMUM STEP SIZE(HMIN)	=	0.0
MAXIMUM STEP SIZE(HMAX)	=	1000.00000
PRINT INTERVAL(DELP)	=	0.00028

If the user desires, he may request element output from the geometry routine (GEOMHT), by inputting KODG equal to one. By doing this, the user will obtain NELEM pages of geometry output, each of which contains the specific heat, thermal conductivity, internal heat generation and boundary condition matrices for a finite element. The symmetric matrices are printed in a lower-triangular rowwise format.

The following sample is output for finite element number one of the rocket motor discretization.

ELEMENT NO. 23

SPECIFIC HEAT

0.56915581E-02 0.29063066E-02 0.59336610E-02 0.29063066E-02 0.29668307E-02 0.59336610E-02

THERMAL CONDUCTIVITY

0.50610256E 01 0.53585484E-06 0.12652473E 01-0.50610266E 01-0.12652483E 01 0.63262730E 01

INTERNAL HEAT GENERATION

0.0 0.0 0.0

BOUNDARY CONVECTION

0.26848924E 00 0.13787150E 00 0.28299665E 00

BOUNDARY FLUX

0.40636086E 00 0.42086816E 00

SURFACE CONVECTION

0.0 0.0 0.0 0.0 0.0 0.0

SURFACE FLUX

0.0 0.0 0.0

The user may request an arbitrary number of outputs from the derivative routine (DERIV) by inputting LIMPT equal to the number of outputs desired (one is usually sufficient). The derivative output details the assembly of the derivative of temperature as the program goes through the element loop in DERIV, and is particularly useful to ascertain that the input has been properly prepared.

The DERIV output displays element node numbers and their associated temperatures, the thermally-averaged conductivity and specific heat, and the nondimensional element matrices and vectors for each element. As in GEOMHT, the symmetric element matrices are printed lower-triangular rowwise. Also included in this output is the step-by-step assembly of the derivative vector. At the completion of the element loop, the global derivative of temperature vector is printed out as "- (K)(T) + (Y) GLOBAL VECTOR."

Following is a sample of the derivative output for the sample problem.

```
ELEMENT NUMBER   23

ELEMENT NODES                   12           13           26

NODAL TEMPERATURES   530.0000  530.0000  530.0000

AVERAGE CONDUCTIVITY = 0.87191992E 01
AVERAGE SPECIFIC HEAT = 0.11017060E 00

SPECIFIC HEAT MATRIX
     0.39190128E-02      0.20011845E-02      0.40857159E-02      0.20011845E-02      0.20428596E-02      0.40857159E-02

THERMAL CONDUCTIVITY MATRIX
     0.15760021E 01      0.16686511E-06      0.39399791E 00     -0.15760031E 01     -0.39399821E 00      0.19700003E 01

Y1 VECTOR
     0.0                 0.0                 0.0

K21 MATRIX
     0.26848924E 00      0.13787150E 00      0.28299665E 00      0.0                 0.0                 0.0

Y21 VECTOR
     0.40636086E 00      0.42086816E 00      0.0

K22 MATRIX
     0.0                 0.0                 0.0                 0.0                 0.0                 0.0

Y22 VECTOR
     0.0                 0.0                 0.0

(K21)*(T) VECTOR
     0.33339169E-01      0.34529407E-01      0.0

(K22)*(T) VECTOR
     0.0                 0.0                 0.0

(K1)*(T) VECTOR
    -0.11920929E-06     -0.11175871E-07     -0.59604645E-07

-(K)(T) VECTOR
    -0.33339050E-01     -0.34529395E-01      0.59604645E-07

-(K)(T)+ (Y) VECTOR
     0.37302178E 00      0.38633871E 00      0.59604645E-07

-(K)(T) + (Y) GLOBAL VECTOR
     0.53922063E 00      0.10784407E 01      0.10786009E 01      0.11901960E 01      0.99961466E 00      0.75829774E 00
     0.85819817E 00      0.10123415E 01      0.10225067E 01      0.10225077E 01      0.10123434E 01      0.85819823E 00
     0.38633871E 00      0.0                 0.14901161E-07      0.18626451E-06     -0.11175871E-06     -0.20489097E-06
    -0.35762787E-06     -0.35762787E-06      0.81956387E-07     -0.13411045E-06      0.18253922E-06     -0.11920929E-06
     0.0                 0.59604645E-07      0.0                 0.0                 0.0                 0.0
     0.0                 0.0                 0.0                 0.0                 0.0                 0.0
     0.0                 0.0                 0.0                 0.0                 0.0                 0.0
     0.0                 0.0                 0.0                 0.0                 0.0                 0.0
     0.0                 0.0                 0.0                 0.0                 0.0                 0.0
     0.0                 0.0                 0.0                 0.0                 0.0                 0.0
     0.0                 0.0                 0.0                 0.0                 0.0                 0.0
     0.0                 0.0                 0.0                 0.0
```

GLOBAL MATRICES

SPECIFIC HEAT GLOBAL MATRIX - HEAT CAPACITY CONDENSED AT THE NODES

0.22131115E-01	0.66810012E-01	0.66814899E-01	0.65987408E-01	0.49660280E-01	0.26299030E-01
0.23779888E-01	0.21276984E-01	0.18993590E-01	0.18579740E-01	0.20451412E-01	0.22941470E-01
0.25459312E-01	0.18367480E-01	0.93896389E-01	0.21528989E 00	0.21531588E 00	0.21112990E 00
0.14979392E 00	0.85538447E-01	0.78009129E-01	0.88068008E-01	0.10599726E 00	0.11410868E 00
0.10516566E 00	0.86589694E-01	0.84696829E-01	0.50910864E-01	0.15685028E 00	0.32040501E 00
0.32045346E 00	0.31381476E 00	0.21697170E 00	0.13016522E 00	0.13040841E 00	0.15401816E 00
0.17023331E 00	0.16252273E 00	0.13774759E 00	0.12184775E 00	0.13017935E 00	0.70117414E-01
0.14562470E 00	0.26535594E 00	0.26540464E 00	0.25952506E 00	0.17358428E 00	0.10974592E 00
0.10368866E 00	0.10267282E 00	0.10263884E 00	0.10264564E 00	0.10267359E 00	0.10409755E 00
0.12392223E 00	0.38814999E-01	0.62140204E-01	0.93419671E-01	0.93442738E-01	0.90966523E-01
0.59946916E-01	0.38784500E-01	0.36915597E-01	0.36714818E-01	0.36699731E-01	0.36707208E-01
0.36713146E-01	0.37324063E-01	0.26275072E-01	0.27133718E-01		

INVERSE GLOBAL SPECIFIC HEAT MATRIX

0.45185242E 02	0.14967816E 02	0.14966722E 02	0.15154406E 02	0.20136810E 02	0.38024216E 02
0.42092338E 02	0.46999130E 02	0.52649338E 02	0.53822052E 02	0.48896378E 02	0.43589172E 02
0.39278351E 02	0.54444046E 02	0.10650037E 02	0.46448994E 01	0.46443386E 01	0.47364197E 01
0.66758375E 01	0.11690649E 02	0.12819012E 02	0.11354860E 02	0.94342051E 01	0.87635746E 01
0.95088072E 01	0.11548718E 02	0.11806817E 02	0.19642166E 02	0.63755064E 01	0.31210489E 01
0.31205778E 01	0.31865931E 01	0.46088953E 01	0.76825438E 01	0.76682167E 01	0.64927406E 01
0.58742905E 01	0.61529846E 01	0.72596550E 01	0.82069626E 01	0.76817093E 01	0.14261792E 02
0.68669662E 01	0.37685223E 01	0.37678308E 01	0.38531923E 01	0.57608900E 01	0.91119556E 01
0.96442556E 01	0.97396755E 01	0.97428999E 01	0.97422552E 01	0.97396021E 01	0.96063738E 01
0.80695772E 01	0.25763229E 02	0.16092636E 02	0.10704383E 02	0.10701740E 02	0.10993054E 02
0.17874084E 02	0.25783493E 02	0.27088806E 02	0.27236954E 02	0.27248154E 02	0.27242599E 02
0.27238190E 02	0.26792358E 02	0.38058884E 02	0.36854507E 02		

The integration output is printed out at time intervals of length DELP if KPRINT = 1, and of slightly longer intervals if KPRINT = 0. Heading each output is the COMOC and user identifying titles for the problem, and the current time and integration step-size.

The dimensional temperature and non-dimensional derivative of temperature are output in either tabular output form, or according to the user supplied output routine which may simulate the geometry of the problem. If the user does not specify a minimum step-size, the program will automatically compute it. Output from QKNINT will then occur when the minimum step-size has been determined.

Following is the initial and final output of the sample problem of a ten-second firing of a small axisymmetric rocket motor.

```
                                     C O M C C

                         COMPUTATIONAL CONTINUUM MECHANICS
                              THERMAL ANALYSIS VARIANT

                   STANDARD TEST CASE FOR COMCC
 104 FINITE ELEMENT DISCRETIZATION OF A SMALL THRUST VECTOR CONTROL
 ROCKET MOTOR, USING TRIANGULAR AXISYMMETRIC RING ELEMENTS WITH VARIABLE
 CONVECTIVE BOUNDARY CONDITIONS APPLIED TO INTERIOR SURFACE. TRANSIENT
 BEHAVIOR DURING A 10 SECOND FIRING DETERMINED USING TEMPERATURE
 DEPENDENT MATERIAL PROPERTIES AND  QKNINT AUTOMATIC INTEGRATOR.


TIME =     0.0       HOURS        CURRENT INTEGRATION STEP SIZE =    0.10000E-05 HOURS

X1-COORDINATE(FT.)
      0.02      0.05      0.08      0.12      0.15                0.18      0.20      0.22      0.23      0.25      0.27                0.30


TEMPERATURE(DEGREES RANKINE)
    530.00    530.00    530.00    530.00
    530.00    530.00    530.00    530.00
                                            530.00                                                                                    530.00
    530.00    530.00    530.00    530.00    530.00    530.00                                                                530.00    530.00
                                                      530.00    530.00    530.00    530.00    530.00    530.00    530.00    530.00
    530.00    530.00    530.00    530.00    530.00              530.00    530.00    530.00    530.00    530.00    530.00              530.00
    530.00    530.00    530.00    530.00              530.00                                                                530.00
                                            530.00              530.00    530.00    530.00    530.00    530.00    530.00              530.00
                                            530.00    530.00                                                                530.00    530.00
                                                      530.00    530.00                                              530.00    530.00
                                                                530.00    530.00                          530.00    530.00
                                                                          530.00    530.00    530.00    530.00
                                                                                    530.00    530.00

TIME DERIVATIVE OF TEMPERATURE(NON-DIMENSIONAL)
      0.00      0.00     -0.00     -0.00
     -0.00      0.00      0.00      0.00
                                             -0.00                                                                                     -0.00
      0.00      0.00      0.00     -0.00      0.00      0.00                                                                  0.00      0.00
                                                        0.00     -0.00     -0.00     -0.00      0.00     -0.00     -0.00     -0.00
      0.00      0.00      0.00     -0.00     -0.00                0.00      0.00       0.0      0.00      0.00      0.00                0.00
      0.54      1.08      1.08      1.19                0.00                                                                 -0.00
                                             -0.00                0.00      0.00       0.0      0.00      0.00      0.00                0.00
                                              1.00     -0.00                                                                  0.00      0.38
                                                        0.76     -0.00                                              0.00      0.76
                                                                  0.86     -0.00                          0.00      0.86
                                                                            1.01      0.00     -0.00      1.01
                                                                                      1.02      1.02

QKNINT
CUMULATIVE NUMBER OF TIMES STEP SIZE WAS DECREASED =          0     AND INCREASED =          0

QKNINT
TIME AT WHICH ACCURACY TEST WAS FIRST FAILED=   0.849999E-04  HOURS
STEP-SIZE AT PREVIOUS TIME STEP             =   0.160000E-04  HOURS
NEW MINIMUM STEP-SIZE (HMIN)                =   0.160000E-04  HOURS
```

C C M C C

COMPUTATIONAL CONTINUUM MECHANICS
THERMAL ANALYSIS VARIANT

STANDARD TEST CASE FOR CCMCC
104 FINITE ELEMENT DISCRETIZATION OF A SMALL THRUST VECTOR CONTROL
ROCKET MOTOR, USING TRIANGULAR AXISYMMETRIC RING ELEMENTS WITH VARIABLE
CONVECTIVE BOUNDARY CONDITIONS APPLIED TO INTERIOR SURFACE. TRANSIENT
BEHAVIOR DURING A 10 SECOND FIRING DETERMINED USING TEMPERATURE
DEPENDENT MATERIAL PROPERTIES AND OKNINT AUTOMATIC INTEGRATOR.

TIME = 0.002885 HOURS CURRENT INTEGRATION STEP SIZE = 0.30400E-03 HOURS

X1-COORDINATE(FT.)

TEMPERATURE(DEGREES RANKINE)

0.02	0.05	0.08	0.12	0.15		0.18	0.20	0.22	0.23	0.25	0.27		0.30
686.92	696.52	691.94	673.16										
727.01	728.82	723.38	704.75										
				791.07									694.35
1009.22	987.57	977.19	946.29	834.00	841.38							778.56	739.89
					892.22	897.43	810.51	756.69	755.38	799.58	854.22	818.04	
1541.16	1505.94	1494.20	1456.06	1134.46		959.34	858.12	799.90	799.10	848.60	919.50		970.45
1873.09	1837.69	1828.46	1797.59		1241.98							1168.99	
				1718.31		1367.61	1229.00	1145.33	1147.29	1227.54	1345.12		1561.37
				2087.82	1902.00							1854.71	1996.51
					2318.89	2123.66					2105.65	2289.90	
						2585.94	2417.28			2385.04	2571.45		
							2925.73	2730.39	2712.61	2906.36			
								3264.56	3257.17				

TIME DERIVATIVE OF TEMPERATURE(NON-DIMENSIONAL)

0.02	0.05	0.08	0.12	0.15		0.18	0.20	0.22	0.23	0.25	0.27		0.30
0.04	0.07	0.06	0.06										
0.11	0.20	0.19	0.18										
				0.06									0.02
0.15	0.31	0.30	0.28	0.18	0.05							0.03	0.03
					0.14	0.05	0.05	0.04	0.04	0.04	0.04	0.13	
0.09	0.21	0.21	0.20	0.26		0.14	0.13	0.13	0.13	0.13	0.13		0.08
0.02	0.06	0.06	0.06		0.18							0.17	
				0.18		0.20	0.26	0.29	0.27	0.22	0.18		0.06
				0.06	0.12							0.11	0.02
					0.03	0.12					0.14	0.03	
						0.04	0.16			0.20	0.03		
							0.04	0.22	0.24	0.04			
								0.04	0.04				

OKNINT
CUMULATIVE NUMBER OF TIMES STEP SIZE WAS DECREASED = 1 AND INCREASED = 22

VI. USER-WRITTEN OUTPUT SUBROUTINE FOR SAMPLE PROBLEM

Contained in this section is a FORTRAN listing of the user generated subroutine which presents output in a format geometrically similar to the sample problem, as was illustrated in Section V. To operate this output feature for any problem, the user sets NOUTP to any non-zero integer and provides COMOC with a routine titled SUBROUTINE OUTPUT. The variables NCOLS and NROWS are then used to set up a specific output format.

```
0001          SUBROUTINE OUTPUT
       C      ----------------------------------------------------------------
       C      USER GENERATED OUTPUT ROUTINE FOR ROCKET MOTOR                      90003
       C      ----------------------------------------------------------------
0002          COMMON / QKNI / YY(2,700), ZZ(2,700), XX(25)
0003          COMMON/COMR/CS(1000,6),AKS(1000,6),FGI(1000,3),ZM(1000,3),
            1           AK2S(1000,6),YM2(1000,3),YM(1000,2),FC(1000),Q(1000),
            2           TR(1000),TK(1000),F(1000),RCOOR(700),ZCOOR(700),T(700),
            3           C(700),TTABC(20,6),TTABK(20,6),TTAERC(20,6), TFIX(100),
            4             CTAB(20,6),AKTAB(20,6),RCTAB(20,6),HEAD(6,18),
            5           ALC,AKC,TRC,TCONST,FTIN,AK2TAB(20,6)                      10009
0004          COMMON/COMI/MELEM(1000),KBND(1000),INODE(3000),NTABC(6),NTABK(6),
            1             NTABRC(6),IOUT(20,30),NCOLS(30),NROWS,IFIX(100),NFIX,
            2        NTITLE,NELEM,NNODE,NCOORD,NN,NNS,IFIRCL,KOD4,KODC,LIMPT
0005          DIMENSION Z(700)
0006          DATA KOUNT/0/
0007          EQUIVALENCE (XX(24),N),(XX(21),NOE)
0008        1 FORMAT (1H0//' TIME =',F12.6,' HOURS',
           1 8X,'CURRENT INTEGRATION STEP SIZE =',E15.5,' HOURS')
0009     1058 FORMAT(1H1,40X,'C O M O C',//30X,'COMPUTATIONAL CONTINUUM MECHANIC
           1S',/34X,'THERMAL ANALYSIS VARIANT',//)
0010     1059 FORMAT(1H ,18A4)
0011     1100 FORMAT(1H ,15(F7.2,1X))
0012     1101 FORMAT(1H0,//,1H ,'TEMPERATURE(DEGREES RANKINE)')
0013     1103 FORMAT(1H0,'TIME DERIVATIVE OF TEMPERATURE(NON-DIMENSIONAL)')
0014     1120 FORMAT(1H0,'X1-COORDINATE(FT.)',/1H ,
            1           5(F7.2,1X),8X,6(F7.2,1X),8X,F7.2)
0015     1200 FORMAT(1H ,32X,F7.2,65X,F7.2)
0016     1205 FORMAT(1H ,6(F7.2,1X),48X,2(F7.2,1X))
0017     1210 FORMAT(1H ,40X,11(F7.2,1X))
0018     1220 FORMAT(1H ,5(F7.2,1X),8X,6(F7.2,1X),8X,F7.2)
0019     1230 FORMAT(1H ,4(F7.2,1X),8X,F7.2,49X,F7.2)
0020     1240 FORMAT(1H ,32X,F7.2,9X,6(F7.2,1X),8X,F7.2)
0021     1250 FORMAT(1H ,32X,2(F7.2,1X),48X,2(F7.2,1X))
0022     1260 FORMAT(1H ,40X,2(F7.2,1X),32X,2(F7.2,1X))
0023     1270 FORMAT(1H ,48X,2(F7.2,1X),16X,2(F7.2,1X))
0024     1280 FORMAT(1H ,56X,4(F7.2,1X))
0025     1290 FORMAT(1H ,64X,2(F7.2,1X))
0026          WRITE(6,1058)
0027          DO 10 I=1,NTITLE
0028       10 WRITE(6,1059)(HEAD(I,J),J=1,18)
0029          TME = XX(15) * TCONST
0030          SS = XX(14) * TCONST
0031          WRITE (6,1) TME,SS
0032          DO 5 I=1,NOE
0033        5 Z (I) =YY(N,I)*C(I)*TRC
0034          DO 2  I=1,NNODE
0035        2 ZCOOR(I) = ZCOOR(I) * ALC
0036          N1 = NCOLS(6)
0037          WRITE(6,1120)(ZCOOR(IOUT(6,J)),J=1,N1)
0038          WRITE(6,1101)
0039          DO 301 I=1,NROWS
0040          N1 = NCOLS(I)
0041          GO TO (11,11,13,14,15,16,17,18,19,20,21,22,23),I
0042       11 WRITE(6,1100)(Z(IOUT(I,J)),J=1,N1)
0043          GO TO 301
0044       13 WRITE(6,1200)(Z(IOUT(I,J)),J=1,N1)
0045          GO TO 301
```

```
   14   WRITE(6,1205)(Z(IOUT(I,J)),J=1,N1)
        GO TO 301
   15   WRITE(6,1210)(Z(IOUT(I,J)),J=1,N1)
        GO TO 301
   16   WRITE(6,1220)(Z(IOUT(I,J)),J=1,N1)
        GO TO 301
   17   WRITE(6,1230)(Z(IOUT(I,J)),J=1,N1)
        GO TO 301
   18   WRITE(6,1240)(Z(IOUT(I,J)),J=1,N1)
        GO TO 301
   19   WRITE(6,1250)(Z(IOUT(I,J)),J=1,N1)
        GO TO 301
   20   WRITE(6,1260)(Z(IOUT(I,J)),J=1,N1)
        GO TO 301
   21   WRITE(6,1270)(Z(IOUT(I,J)),J=1,N1)
        GO TO 301
   22   WRITE(6,1280)(Z(IOUT(I,J)),J=1,N1)
        GO TO 301
   23   WRITE(6,1290)(Z(IOUT(I,J)),J=1,N1)
  301   CONTINUE
        WRITE(6,1103)
        DO 311 I=1,NROWS
        N1 = NCOLS(I)
        GO TO (31,31,33,34,35,36,37,38,39,40,41,42,43),I
   31   WRITE(6,1100)(ZZ(N, IOUT(I,J)),J=1,N1)
        GO TO 311
   33   WRITE(6,1200)(ZZ(N,IOUT(I,J)),J=1,N1)
        GO TO 311
   34   WRITE(6,1205)(ZZ(N,IOUT(I,J)),J=1,N1)
        GO TO 311
   35   WRITE(6,1210)(ZZ(N,IOUT(I,J)),J=1,N1)
        GO TO 311
   36   WRITE(6,1220)(ZZ(N,IOUT(I,J)),J=1,N1)
        GO TO 311
   37   WRITE(6,1230)(ZZ(N,IOUT(I,J)),J=1,N1)
        GO TO 311
   38   WRITE(6,1240)(ZZ(N,IOUT(I,J)),J=1,N1)
        GO TO 311
   39   WRITE(6,1250)(ZZ(N,IOUT(I,J)),J=1,N1)
        GO TO 311
   40   WRITE(6,1260)(ZZ(N,IOUT(I,J)),J=1,N1)
        GO TO 311
   41   WRITE(6,1270)(ZZ(N,IOUT(I,J)),J=1,N1)
        GO TO 311
   42   WRITE(6,1280)(ZZ(N,IOUT(I,J)),J=1,N1)
        GO TO 311
   43   WRITE(6,1290)(ZZ(N,IOUT(I,J)),J=1,N1)
  311   CONTINUE
        DO 320 I=1,NNODE
  320   ZCOOR(I) = ZCOOR(I) / ALC
        KOUNT=KOUNT+1
        IF (LIMPT .GT. KOUNT) KOD4=1
        RETURN
        END
```