(NASA-CR-168191) RESEARCH AND DEVELOPMENT PROGRAM FOR THE DEVELOPMENT OF ADVANCED TIME-TEMPERATURE DEPENDENT CONSTITUTIVE RELATIONSHIPS. VOLUME 2: PROGRAMMING MANUAL Final Report (United Technologies

N84-10614

Unclas

G3/39 44342

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-168191		

4. Title and Subtitle
Research and Development Program for the Development of Advanced Time-Temperature Dependent Constitutive Relationships - Vol. 2 - Programming Manual

5. Report Date
July 1983

6. Performing Organization Code

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8. Performing Organization Report No.
R83-956077-2

9. Performing Organization Name and Address
United Technologies Research Center
400 Main Street
East Hartford, CT 06108

10. Work Unit No.

11. Contract or Grant No.
NAS3-23273

12. Sponsoring Agency Name and Address
NASA/Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

13. Type of Report and Period Covered
Contractor Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
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National Aeronautics and Space Administration
Lewis Research Center, 21000 Brookpark Road,
Cleveland, Ohio 44135

16. Abstract
This report presents the results of a 10-month research and development program for nonlinear structural modeling with advanced time-temperature constitutive relationships. This program was conducted by the United Technologies Research Center for the NASA-Lewis Research Center under contract NAS3-23273. This manual describes the implementation of the theory, discussed in Vol. 1, in the MARC nonlinear finite element code, and provides instructions for the computational application of the theory.

17. Key Words (Suggested by Author(s))
Gas Turbine Engines, Creep, Plasticity, Visco-Plasticity, Constitutive Relationship, Thermovisco-Plasticity, Inelastic

18. Distribution Statement
Unlimited, Unclassified

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

Research and Development Program for the Development of Advanced Time-Temperature Dependent Constitutive Relationships

Vol. 2 - Programming Manual

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1.0 INTRODUCTION

The theory described in Vol. 1 has been implemented in the MARC nonlinear finite element code, Ref. 1. Several modifications to the code are required to insure accurate results. The major modification is through the MARC user subroutine HYPELA. Section 2.0 contains a brief description of the MARC code, while Section 3.0 discusses the inputs to subroutine HYPELA. Section 4.0 presents the control parameters and data cards required to efficiently integrate the viscoplastic equations presented in Appendix 14 of Vol. 1.

2.0 DESCRIPTION OF THE MARC PROGRAM

The viscoplastic theories presented in Volume 1 have been incorporated into the MARC general purpose, nonlinear, finite element program, Ref. 1. This program has been developed expressly for nonlinear structural analysis. This computer code involves sophisticated computational algorithms and advanced finite element formulations, but relies on constitutive models not directly applicable to hot section components.

In this contract, as in the previous contract (Ref. 2), the viscoplastic constitutive theories were incorporated into the MARC program by means of an initial stress technique. All of the material nonlinearity in the constitutive equations is incorporated into an initial load vector and treated as a pseudo body force in the finite element equilibrium equations. Because the viscoplastic constitutive theories form a "stiff" system of differential equations, it is necessary to form the incremental constitutive equation appropriate to the finite element load increment by means of a subincrement technique.

In the subincrement technique the finite element load increment is split into a number of equal subincrements and the viscoplastic constitutive theories are integrated over the small subincrements to form an accurate representation of the incremental constitutive equation over the finite element load increment. Integration over each subincrement was accomplished by means of an explicit Euler forward difference method. Provided the subincrements are sufficiently small (so that the stability level of the forward difference method is not exceeded), the technique has been found to work efficiently and accurately, even for large finite element load increments. However, it is difficult for the user to pick efficient subincremental steps, and there is a considerable incentive to use as few subincrements as possible, consistent with the stability of the differential equations comprising the constitutive theory.

In order to understand the flow of information, it is necessary to briefly examine the MARC code operation. A summary of the operation of the MARC nonlinear finite element, taken from Ref. 2, follows.

The principle of virtual work may be used to generate the MARC nonlinear equilibrium equations governing the incremental response of the structure to an increment of load. In evaluating the nonlinear structural response of a component, the program assumes that the load history is divided into a number of incrementally applied load steps. Each load step is sequentially analyzed as a linear matrix problem using an appropriate stiffness matrix and load vector. Although each load step uses linear matrix methods to solve the incremental equilibrium equations, the incremental equilibrium equations themselves are nonlinear since the load vector will depend on the displacement increment obtained in the solution of the incremental equilibrium equations.

The principle of virtual work may be written, for applied external point loads P_i, or displacements u_i, in the form

$$\Sigma \int_v \delta\epsilon_i^T \sigma_i \, dV = \delta u_i^T P_i \ , \qquad (1)$$

where the integral extends over the volume, V, of each finite element and the summation sign extends to all the elements in the structure.

In Eq. (1) the virtual displacement vector δu_i is related to the virtual strain vector $\delta \varepsilon_i$ through the relationship

$$\delta\epsilon_i = B_{ij} \delta u_j \text{ or } \delta\epsilon_i^T = \delta u_j^T B_{ij}^T, \qquad (2)$$

where B_{ij} is the strain-displacement matrix and the superscript T denotes transposition. Since δu_i is an arbitrary virtual displacement vector, Eqs. (1) and (2) may be written in the form

$$\Sigma \int_v B_{ij}^T \sigma_j \, dV = P_i \ . \qquad (3)$$

This relation expresses the equilibrium of the structure when the applied load vector is P_i and the stress vector is σ_i. If an incremental load ΔP_i is applied to the structure and the stress vector changes to $\sigma_i + \Delta\sigma_i$, the relation expressing the equilibrium of the structure at the end of the incremental load application may be written as

$$\Sigma \int_v B_{ij}^T (\sigma_j + \Delta\sigma_j) \, dV = P_i + \Delta P_i \ . \qquad (4)$$

Hence, the relation expressing the equilibrium of the structure during the application of the incremental load vector ΔP_i is obtained from Eqs. (3) and (4) by subtraction in the form

$$\Sigma \int_v B_{ij}^T \Delta\sigma_j \, dV = \Delta P_i \ . \qquad (5)$$

The MARC code allows the user to implement very general constitutive relationships into the program by means of the user subroutine HYPELA. Within this subroutine the user must specify the values of the elasticity matrix D_{ij} and the inelastic stress increment vector $\Delta\zeta_i$ in the incremental vector constitutive relationship

$$\Delta\sigma_i = D_{ij}(\Delta\epsilon_j - \delta_j \alpha \Delta\Theta) - \Delta\zeta_i \tag{6}$$

The inelastic stress increment vector $\Delta\zeta_i$ is computed in HYPELA from the viscoplastic constitutive relationships programmed in the Appendices.

In Eq. (6) α dnotes the coefficient of thermal expansion and δ_j is the vector Kronecker delta symbol,

$$\delta_j = \begin{cases} 1 \text{ if } 0 \leq j \leq 3 \\ 0 \text{ if } 3 < j \leq 6 \end{cases} \tag{7}$$

For the class of nonlinear visoplastic constitutive relationships under consideration in this contract, the incremental inelastic stress vector $\Delta\zeta_i$ depends in a highly nonlinear manner on the incremental strain vector $\Delta\varepsilon_i$. Since $\Delta\varepsilon_i = B_{ij}\,\Delta u_j$, the incremental inelastic stress vector $\Delta\zeta_i$ depends in a highly nonlinear manner on the nodal displacement vector increment Δu_j, so that $\Delta\zeta_i = \Delta\zeta_i\,(\Delta u_j)$.

Substitution of Eq. (6) into (5) produces the incremental equilibrium equations for MARC in the form,

$$\sum K_{ij}\,\Delta u_j = \Delta P_i + \Delta R_i + \sum\int_V B_{ij}^T \Delta\zeta_j\, dv + \sum\int_V B_{ij}^T \delta_j \alpha \Delta\Theta\, dv\,, \tag{8}$$

where K_{ij} is the elemental elastic stiffness matrix defined by the relation

$$K_{ij} = \int_V B_{ik}^T D_{k\ell} B_{\ell j}\, dV. \tag{9}$$

The vector ΔR_i is the residual load correction vector or out-of-equilibrium force vector from the preceding load increment,

$$\Delta R_i = P_i - \sum\int_V B_{ij}\sigma_j\, dV\,, \tag{10}$$

which is added to the current increment in order to restore the structure to equilibrium. The nonlinearity in the incremental equilibrium relationship, defined in Eq. (8), arises because the inelastic stress increment vector $\Delta\zeta_i$ depends nonlinearly on the displacement increment vector Δu_j. Values of D_{ij} and $\Delta\zeta_j$ appropriate to the current incremental load step are returned to the main program by subroutine HYPELA and the incremental equilibrium relations in Eq. (8) are solved by successive iterations.

The solution of the incremental equilibrium equations in (8) is accomplished within the MARC code by the following algorithm. At the start of the increment the user subroutine HYPELA is entered to determine the elasticity matrix D_{ij} and the incremental inelastic stress vector $\Delta\zeta_i$. On entry to the subroutine the input consists of the strain increment vector $\Delta\varepsilon_i$, the temperature increment $\Delta\theta$, the time increment Δt over which the incremental external load vector ΔP_i is applied to the structure, and the values of the stress, strain, temperature and viscoplastic state variables at the beginning of the increment. Since the incremental strain vector, $\Delta\varepsilon_i = B_{ij}\Delta u_j$, can only be accurately determined after the solution to the incremental equilibrium relationship in Eq. (8) has yielded the correct incremental solution vector Δu_j, the strain increment vector $\Delta\varepsilon_i$ initially used to generate the inelastic stress increment vector $\Delta\zeta_i$ must be estimated. The initial estimate for $\Delta\varepsilon_i$ is assumed to be the value obtained for $\Delta\varepsilon_i$ in the preceding increment. On exit from subroutine HYPELA the elasticity matrix D_{ij} and the estimated inelastic stress increment vector $\Delta\zeta_j$ are passed into the main program. After the values of D_{ij} and $\Delta\zeta_j$ are obtained for each integration point in the structure. the incremental equilibrium relationship in Eq. (8) is assembled and solved for the incremental node displacement vector Δu_j. The incremental strain vector, $\Delta\varepsilon_i = B_{ij}\Delta u_j$, is then computed and compared with the initial guess for $\Delta\varepsilon_i$ used to generate the inelastic incremental stress vector $\Delta\zeta_j$. If this incremental strain vector is equal, within a user specified tolerance, to the incremental strain vector used to compute $\Delta\zeta_j$ in the assembly phase, the solution is assumed to have converged. Otherwise, the updated strain increment vector, obtained from the solution of the equilibrium relations in Eq. 8), is passed into subroutine HYPELA, a new vector, $\Delta\zeta_j$, is computed, and the equilibrium equations resolved to yield an improved value of Δu_i and $\Delta\varepsilon_i$. The process is repeated until the value of the vector $\Delta\varepsilon_i$ on the assembly phase is equal, within a user specified tolerance, to the value of the vector $\Delta\varepsilon_i$ on the solution phase. After convergence is achieved, the temperature, stress vector, strain vector and viscoplastic state variables are updated by adding the incremental values generated during the current increment to the values of these variables at the beginning of the increment. The program then passes on to the next load increment where the process is repeated. A flow chart of the iterative procedure required to implement viscoplastic constitutive theories into the MARC program is shown in Fig. 1.

3.0 IMPLEMENTATION OF VISCOPLASTIC THEORY IN MARC

The integration of the viscoplastic theory described in Vol. 1 can be introduced into the MARC code by means of the user subroutine HYPELA. This routine is called at each integration point in each element and supplies the elasticity matrix D_{ij} and the inelastic stress increment vector $\Delta\zeta_j$ to the main program.

The required header cards are:

```
 SUBROUTINE HYPELA(D,G,E,DE,S,TEMP, DTEMP,NGENS,N,NN,KC,MAT,NDI,
1NSHEAR)
 DIMENSION D(NGENS,NGENS),G(NGENS),E(NGENS),DE(NGENS),S(NGENS)
 DIMENSION TEMP(1), DTEMP(1)
     :
 FORTRAN CODING
     :
 RETURN

 END
```

where

D(NGENS,NGENS)	is the elasticity matrix D_{ij} defined in this subroutine (output argument),
G(NGENS)	is the inelastic stress increment vector $\Delta\zeta_j$ defined in this subroutine (output argument),
E(NGENS)	is the mechanical strain $\epsilon_i - \delta_i \int_0^t \alpha(\xi)[\partial\Theta(\xi)/\partial\xi]d\xi$ at the beginning of the increment (input argument),
DE(NGENS)	is the increment of mechanical strain $\Delta\epsilon_i - \delta_i\alpha\Delta\Theta$ (input argument),
S(NGENS)	is the stress σ_i at the beginning of the increment (input argument),
TEMP(1)	is the temperature Θ at the beginning of the increment (input argument),
TEMP(2)	is the time t at the beginning of the increment (input argument),

TEMP(3)	is the cumulative inelastic strain R at the beginning of the increment (input argument),
TEMP(4) through TEMP(9)	are the values of the inelastic strains, c_1 through c_6, at the beginning of the increment (input argument),
TEMP(10) through TEMP(15)	are the values of the equilibrium stresses Ω_1 through Ω_6 at the beginning of the increment (input argument),
TEMP(16)	is the number of subincrements used to integrate the last MARC increment,
DTEMP(1)	is the temperature increment $\Delta\Theta$ (input argument),
DTEMP(2)	is the time increment Δt (input argument),
DTEMP(3)	is the increment of cumulative inelastic strain ΔR (output argument)
DTEMP(4) through DTEMP(9)	are the incremental values of inelastic strain Δc_1 through Δc_6 (output argument),
DTEMP(10) through DTEMP(15)	are the incremental values of the equilibrium stress $\Delta\Omega_1$ through $\Delta\Omega_6$ (output argument),
DTEMP(16)	is output as zero, since the NSPLIT is updated automatically,
NGENS	is the size of the D_{ij} matrix (NGENS = 3 for plane stress problems, NGENS = 4 for plane strain and axisymmetric problems, NGENS = 6 for three dimensional problems) (input argument),
N	is the finite element number (input argument),
NN	is the integration point number (input argument),
KC	is the layer number in shell or beam problems (input argument),
MAT	is the material identifier (input argument),

NDI	is the number of direct stress components (NDI = 2 for plane stress problems, NDI = 3 for plane strain, axisymmetric and three dimensional problems) (input argument)
NSHEAR	is the number of shear components (NSHEAR = 1 f... plane stress, plane strain and axisymmetric problems. NSHEAR = 3 for three dimensional problems) (input argument)

4.0 INTEGRATION OF VISCOPLASTIC EQUATIONS IN SUBROUTINE HYPELA

4.1 Self Adaptive Integration

The values of D_{ij} and $\Delta\zeta_i$ in the incremental constitutive relation,

$$\Delta\sigma_i = D_{ij}(\Delta\epsilon_j - \delta_j \alpha \Delta\Theta) - \Delta\zeta_i \,. \tag{11}$$

are obtained by a subincrement method. Incremental values of the variables $\Delta\Theta$, Δt and $(\Delta\epsilon_i - \delta_i\alpha\Delta\Theta)$ for the current finite element load increment are split into NSPLIT equal values, and the constitutive equations are integrated over the NSPLIT subincrements to provide accurate values of D_{ij} and $\Delta\zeta_i$. The subroutine HYPELA (Appendix 1) integrates Walker's viscoplastic equations and calls subroutine HYPCON (Appendix 2) to evaluate the material parameters. HYPCON contains the latest estimates for the parameters in the modified Walker's Theory described in Vol. 1. Each load increment in a MARC analysis is divided into NSPLIT subincrements. The integration of the constitutive equations is performed by using forward differences with a step size determined by dividing the MARC load increment by NSPLIT. Subroutine HYPELA performs the integration in two ways: (1) a fixed step size, or (2) a variable step size. In the fixed step size forward difference (KEY equal to one at line 32 of HYPELA), NSPLIT is the same for all MARC load increments and subincrements.

In the variable step size forward difference (KEY equal to zero in line 32 of HYPELA), NSPLIT is determined by the magnitude of the change in a strain measure for every subincrement. The change in the strain measure is defined as

$$E = \Delta R + \frac{\sqrt{3\Delta J_2}}{2\mu} \tag{12}$$

where

$$\Delta R = \sqrt{\tfrac{2}{3}\Delta C_{ij}\Delta C_{ij}} \tag{13}$$

$$\Delta J_2 = \frac{3}{2}\,\Delta S_{ij}\,\Delta S_{ij} \text{ and} \tag{14}$$

the quantity $\Delta\bar{\varepsilon}$ is calculated in line 324 of HYPELA and is stored as variable ERRORO. There are three possible ways to determine NSPLIT. The method depends on the size of ERRORO. If

$$\text{ERROR2} < \text{ERRORO} < \text{ERROR1} \tag{15}$$

Then NSPLIT remains the same for the next subincrement (ERROR1 and ERROR2 are specified in lines 54 and 55 of HYPELA). If

$$\text{ERRORO} < \text{ERROR2} \tag{16}$$

NSPLIT is divided in two for the next subincrement and rounded (up) to the nearest integer. If

$$\text{ERRORO} > \text{ERROR1} \tag{17}$$

then NSPLIT is doubled and the step is recomputed. The value of NSPLIT at the end of the increment is stored in the state variable TEMP(16). The initial value of NSPLIT can be specified in an INITIAL STATE BLOCK in the MARC model definition cards or in line 31 of HYPELA. The maximum value of NSPLIT is specified by MXSPLT (line 57 of HYPELA). If NSPLIT exceeds MXSPLT the message:

"UNABLE TO REDUCE ERROR IN LESS THAN <u>MXSPLT</u> SUBINCREMENTS"

is written where the value of MXSPLT is inserted in the WRITE statement. After this condition is satisfied the integration is performed using a constant step size.

4.2 Time Independent Terms and Rate of Change of Temperature Terms

Two remaining variables must be specified in HYPELA: NONISO (line 64 of HYPELA) and INDEP (line 67 of HYPELA). If

$$\text{NONISO} = 1 \tag{18}$$

the change in temperature with respect to time terms will be included. If

$$\text{NONISO} = 0 \tag{19}$$

these terms will not be included. If

$$\text{INDEP} = 1 \tag{20}$$

the time independent terms will be included. If

$$\text{INDEP} = 0 \tag{21}$$

these terms will not be included.

4.3 Modifications to Other MARC Subroutines

In order to run viscoplastic models in a more efficient manner, the MARC code can be modified to run using a constant inverted stiffness matrix. Such a modification eliminates the requirement to reassemble and invert the stiffness matrix with a subsequent savings in CPU time. This can be accomplished, for example, by: (1) changing line 65 of subroutine THRUH (Appendix 3) to

$$\text{LOADUQ} = 0 \tag{22}$$

(2) changing line 116 of subroutine INCDT1 (Appendix 4) to

IASMBL = 0, and

(3) changing line 208 of subroutin INCDT1 to

IASMBL = 0

To insure proper runs only the appropriate lines specifying IASMBL in subroutines INCDT1 and INCDT2 should be changed. For example, if only BOUNDARY CHANGE cards are used in the load incrementation part of the MARC input, then only line 208 of INCDT1 for specifying IASMBL needs to be changed (along with line 65 of THRUH).

Line 753 of the MARC subroutine STEG needs to be changed to that shown in Appendix 5 to insure proper running of the MARC code when using HYPELA.

4.4 HYPELA Control Parameters

The subroutine HYPCON, which calculates the temperature dependent material parameters, is called four times by HYPELA at lines 68, 188, 193 and 198. Each of these calls evaluates the material parameters at a different temperature. The first call determines the elastic constants for which the stiffness matrix is generated, and will be the same on all increments. The second through the fourth calls evaluate the material constants at the median temperature of the subincrement, at the beginning of the subincrement and at the end of the subincrement, respectively.

The stiffness matrix is generated with the elastic constants determined by the temperature variable SFTEMP (see line 59 of HYPELA).

MARC solves the incremental equilibrium Eq. (8) by successive iteration. To see how the equilibrium equation iterations are converging one can pick the integration point, NPRIN, at line 51 of HYPELA, in element number, NELPR, at line 40 of HYPELA, at which the maximum amount of nonlinearity is expected. As subroutine

HYPELA is entered on the assembly phase the routine prints out the strain increment vector $\Delta\varepsilon_i$ and the stress increment vector $\Delta\sigma_i$ at integration point NPRIN in element number NELPR. After the equilibrium equations have been solved for the incremental displacement vector Δu_i, subroutine HYPELA is again entered with $\Delta\varepsilon_i = B_{ij}\Delta u_j$ and the incremental vectors are printed out on the assembly and solution phase of every successive iteration of the equilibrium equations. In this way the convergence of the solution to the incremental equilibrium equations can be followed. If no printout of the incremental vectors is required, the variable IPR at line 50 of HYPELA, is set equal to zero.

In order to use subroutine HYPELA, several constants must be defined in the subroutine, starting at card number thirty-one (31). These constants are:

MXSPLT = maximum number of subincrements allowed,

NELPR = element number for printout of incremental stress and strain vectors,

IPR = 1 if stress-strain increment output is required, 0 if stress-strain increment output is not required

NPRIN = integration point number for printout of incremental stress and strain vectors,

NSPLIT = number of subincrements per MARC increment,

SFTEMP = reference temperature for calculating elastic constants

ERROR2 = minimum change in strain measure (Eq. 12) allowed before a subincrement step size

ERROR1 = maximum change in strain measure (Eq. 12) allowed before halving subincrement step size

NONISO = 1 to include rate of change of temperature terms, and equals zero if these terms are not included

INDEP = 1 to include time independent terms, and equals zero if these terms are not included.

In Appendices 6, 7 and 8 are listings of the data input to simulate the three thermomechanical fatigue cycles described in Volume 1.

4.5 MARC Input Data Set

In the MARC input data deck two cards are required in the parameter set before the END card. These are:

```
HYPOELAS
STATE VARS          16
```

4.6 Temperature Input

A uniform temperature increment over the structure, together with an appropriate time increment, can be specified with the following cards:

```
THERMAL LOADS
1,
5.0, 2.0
BLANK CARD
```

In the above sequence of cards, the first state variable increment of 5.0 refers to the uniform temperature increment $\Delta\Theta = 5°F$ over the structure. The second state variable increment of 2.0 refers to a time increment of $\Delta t = 2$ seconds. The remainder of the card and the following BLANK card set the remaining fourteen (14) state variable increments to zero. Since the STATE VARS card defines sixteen (16) state variables, MARC expects this number as input. However, only the first two state variables, $\Delta\Theta$ and Δt are required as input by HYPELA. The remaining (14) state variable increments are defined within subroutine HYPELA.

If a nonuniform temperature over the structure is required (the usual case), the temperature increments and time increment must be set in user subroutine CREDE. This can be accomplished with the following header cards:

```
SUBROUTINE CREDE(DTDL,M,NSTRES,NEQST,NSTATS)
DIMENSION DTDL(NSTATS,NEQST,NSTRES)
COMMON/FAR/DUM,L

N = (where N = number of integration points in element number M)

DO 2 II = 1, N
```

DTDL(1,1,II) = temperature increment at integration point II

DTDL(2,1,II) = time increment (can be made a function of load increment number L)

```
2 CONTINUE
RETURN
END
```

5.0 REFERENCES

1. MARC General-Purpose Finite Element Program, MARC Corporation, Palo Alto, CA.

2. Walker, K. P.: Research and Development Program for Nonlinear Structural Modeling with Advanced Time-Temperature Dependent Constitutive Relationships. Final Report NASA CR-165533, November 1981.

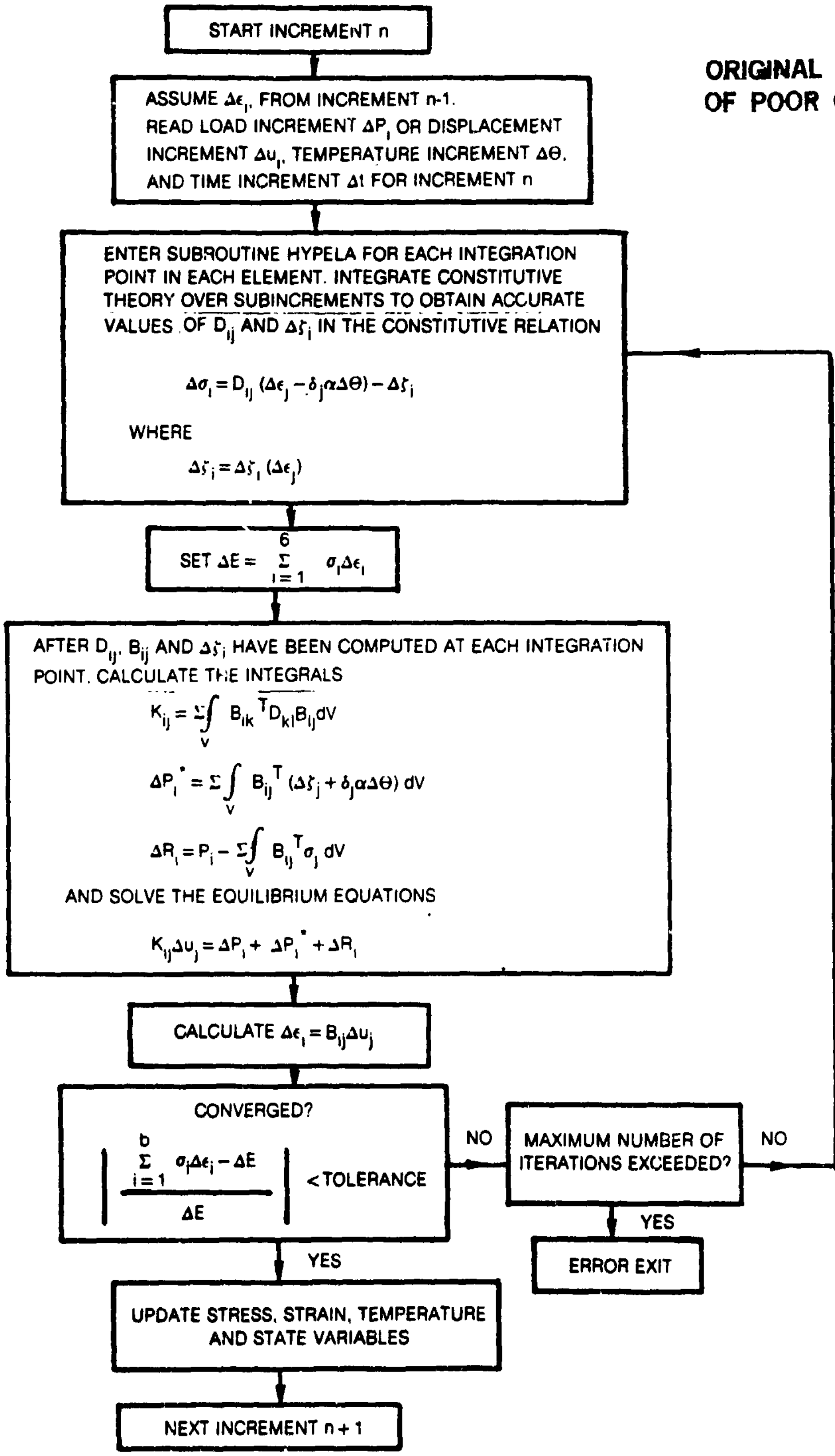

Figure 1. Flow Chart of MARC Iteration Procedure

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APPENDIX 1. SUBROUTINE HYPELA

```
      SUBROUTINE HYPELA(D,G,E,DE,S,TEMP,DTEMP,NGENS,N,NN,KC,MAT,NDI,
     1NSHEAR)
      DIMENSION D(NGENS,NGENS),G(NGENS),E(NGENS),DE(NGENS),S(NGENS)
      DIMENSION TEMP(1),DTEMP(1)
      DIMENSION DSIG(6),DOMEG(6)
      DIMENSION SIG(6),OMEG(6),C(6)
      DIMENSION DC(6),DET(6),OMEGI(6),AB(6)
      DIMENSION SUMSIG(6),ET(6),DS(6),ETI(6)
      DIMENSION DEV(6),OV(6),DAB(6),CI(6)
      COMMON/AKEV/KEVIN
      COMMON/FAR/DUM,INC
      COMMON/CDC/ICROUT,NUPTRA,NCPIN,NCYCM,TOLER,XFAC,FLAMB,FRCTOL,MINC,
     1NINST1,NINST2,NDUM,SCALE,NYD,IDESP,NFCQ,FACS,DISPRE,NCYCLE
C*****SECOND INVARIANT FUNCTION
      SINV(A,B,C,D,E,F)=(A*A+B*B+C*C+2.*(D*D+E*E+F*F))*2./3.
 1234 CONTINUE
C*****
C*****THIS SUBROUTINE RETURNS THE ELASTICITY MATRIX D AND INELASTIC STRESS
C*****INCREMENT G FOR THE WALKER'S  THEORY (B.N.CASSENTI UTRC)
C*****USING THE DIFFERENTIAL FORM OF THE THEORY
C*****EQUATIONS ARE INTEGRATED USING A FOWARD DIFFERENCE
C*****WITH ERROR ESTIMATES FOR REVISING TIME STEPS
C*****
C
C     FOR SELF ADAPTIVE INTEGRATION SET KEY=0
C     FOR FIXED STEP INTEGRATION SET KEY=1 AND
C        (1) SET NSPLIT IN TEMP(16) THROUGH AN INITIAL STATE BLOCK AND/OR
C        (2) SET NSPLIT IN THE IF STATEMENT BELOW
C
      NSPLIT=TEMP(16)
      IF (NSPLIT.LT..999)NSPLIT=16
      KEY=1
      IF(N.NE.1) GO TO 7
      IF(NN.NE.1) GO TO 7
      IF(NCYCLE.EQ.0) NWALK=0
      NWALK=NWALK+1
      NQ=NWALK-2*NCYCLE
      NQQ=NCYCLE-1
C*****DETERMINE IF PLANE STRESS,PLANE STRAIN,AXISYMMETRIC,OR 3-D
C*****KELTYP=1 FOR PLANE STRAIN AND AXISYMMETRIC PROBLEMS
C*****KELTYP=2 FOR PLANE STRESS PROBLEM
C*****KELTYP=3 FOR 3-D PROBLEM
    7 IF(NDI.EQ.3.AND.NSHEAR.EQ.1) KELTYP=1
      IF(NDI.EQ.2.AND.NSHEAR.EQ.1) KELTYP=2
      IF(NDI.EQ.3.AND.NSHEAR.EQ.3) KELTYP=3
C*****SET UP CONSTANTS
      IF(INC.EQ.0 .AND. ABS(DTEMP(1)) .LT. 1.E-9)DTEMP(1)=1.E-12
      IF(INC.EQ.0 .AND. ABS(DTEMP(2)) .LT. 1.E-9)DTEMP(2)=1.E-2
      NELPR=1
      IPR=1
      NPRIN=1
      IF ((INC+NCYCLE) .NE. 0) NSPLIT=TEMP(16)
C     ERROR1 IS MAXIMUM ALLOWABLE STRAIN STEP SIZE
      ERROR1=1.E-4
      ERROR2=ERROR1/10.
C     MXSPLT IS THE MAXIMUM VALUE OF NSPLIT ALLOWED
      MXSPLT=65
      IF (KEY .EQ. 1) MXSPLT=NSPLIT
      SFTEMP=940.
      DEGM=SFTEMP
      IF (TEMP(1) .GT. 1.E-9) SFTEMP=TEMP(1)
C****NONISO=0 WILL NOT INCLUDE DTEMP/DTIME TERMS
C****NONISO=1 WILL INTERPOLATE TO INCLUDE DTEMP/DTIME TERMS
      NONISO=0
C****INDEP=0 TIME INDEPENDENT TERMS NOT INCLUDED
C****INDEP=1 TIME INDEPENDENT TERMS ARE INCLUDED
      INDEP=1
      CALL HYPCON(INDEP,NONISO,DEGM,
```

```
     1 EEM,ANUM,AK1M,AK2M,ANINM,AMM,AN1M,AN2M,AN3M,AN4M,AN5M,AN6M,AN7M,
     2 OMEGOM,AKINDM,SIINFM,DN1DTM,DN2DTM,DOMDTM,
     3 ANM,ALAMM,AMUM,C1M,C2M,C3M,C4M,C5M)
C*****SET ZERO STRAIN INCREMENTS = 1.E-8 TO AVOID DIVISION BY ZERO
      DESINV=SINV(DE(1),DE(2),DE(3),DE(4),DE(5),DE(6))
      DO 1 J=1,NGENS
      IF(DESINV.EQ.0.) DE(J)=1.E-8
    1 CONTINUE
C*****PUT STRESSES AT BEGINNING OF MARC INCREMENT INTO SIGB ARRAY ACCORDING
C*****TO ELEMENT TYPE
      GO TO(801,802,803),KELTYP
  801 CONTINUE
      SIG(1)=S(1)
      SIG(2)=S(2)
      SIG(3)=S(3)
      SIG(4)=S(4)
      SIG(5)=0.
      SIG(6)=0.
      GO TO 900
  802 CONTINUE
      SIG(1)=S(1)
      SIG(2)=S(2)
      SIG(3)=0.
      SIG(4)=S(3)
      SIG(5)=0.
      SIG(6)=0.
      GO TO 900
  803 DO 804 J=1,6
      SIG(J)=S(J)
  804 CONTINUE
  900 CONTINUE
C*****INITIALIZE STATE VARIABLES ON FIRST ENTRY TO SUBROUTINE. ON SECOND
C*****AND SUBSEQUENT ENTRIES SKIP INITIALIZATION.
      KEVIN=INC+NCYCLE
      IF(KEVIN.NE.0) GO TO 3
      IF (TEMP(1) .GT. 1.E-9) SFTEMP=TEMP(1)
      IF (TEMP(1) .LT. 1.E-9) TEMP(1)=SFTEMP
      DO 2 J=2,15
      TEMP(J)=1.E-9
    2 CONTINUE
    3 CONTINUE
C*****SET STARTING VALUES OF STATE VARIABLES DURING PRESENT MARC INCREMENT
      DEG=TEMP(1)
      T=TEMP(2)
      R=TEMP(3)
      DO 104 KA=1,6
      J=KA+3
      OMEG(KA)=TEMP(J)
      C(KA)=TEMP(J+6)
      SUMSIG(KA)=0.
  104 CONTINUE
      KSTEP=0
      ERRORO=0.
C*****START INTEGRATION STEP OVER SUBINCREMENT
 5    SPLIT=NSPLIT
      KSTEP=KSTEP+1
C     WRITE (6,4271) KSTEP,NSPLIT,ERRORO,T
C4271 FORMAT (1H ,'KSTEP= ',I5,5X,'NSPLIT= ',I5,5X,'ERRORO= ',1PE10.3,5X
C    1,'TIME= ',1PE10.3)
      IF (NSPLIT .LE. MXSPLT)GOTO4274
      IF (KEY .EQ. 0) WRITE(6,4273) MXSPLT
 4273  FORMAT
     1(1H ,'***************************************************************'/
     2 1H ,'UNABLE TO REDUCE ERROR IN LESS THAN ',I5,' SUBINCREMENTS'/
     3 1H ,'***************************************************************'/)
      KEY=1
 4274 IF (ABS(T-(TEMP(2)+DTEMP(2))) .GT. ABS(DTEMP(2)/SPLIT))GOTO6
      SPLIT=DTEMP(2)/(TEMP(2)+DTEMP(2)-T)
      IF (ABS((TEMP(2)+DTEMP(2)-T)/DTEMP(2)) .LT. 1.E-3) GOTO420
C*****SET TEMPERATURE AND TIME SUBINCREMENTS
 6    DDEG=DTEMP(1)/SPLIT
      DT=DTEMP(2)/SPLIT
C*****SET STARTING VALUES FOR DEVIATORIC STRESSES
      PRESS=(SIG(1)+SIG(2)+SIG(3))/3.
```

```
      DO 7777 J=1,6
      ALPHA=1.
      IF(J.GT.3)ALPHA=0.
      DEV(J)=SIG(J)-ALPHA*PRESS
 7777 CONTINUE
C*****PUT SUBINCREMENTS OF TOTAL STRAIN INTO ARRAY DET ACCORDING
C*****ELEMENT TYPE
      GO TO(61,62,63),KELTYP
   61 CONTINUE
      DET(1)=DE(1)/SPLIT
      DET(2)=DE(2)/SPLIT
      DET(3)=DE(3)/SPLIT
      DET(4)=0.5*DE(4)/SPLIT
      DET(5)=0.
      DET(6)=0.
      ET(1)=E(1)
      ET(2)=E(2)
      ET(3)=E(3)
      ET(4)=0.5*E(4)
      ET(5)=0.
      ET(6)=0.
      GO TO 71
   62 DET(1)=DE(1)/SPLIT
      DET(2)=DE(2)/SPLIT
      DET(3)=-DET(1)-DET(2)
      DET(4)=0.5*DE(3)/SPLIT
      DET(5)=0.
      DET(6)=0.
      ET(1)=E(1)
      ET(2)=E(2)
      ET(3)=-ET(1)-ET(2)
      ET(4)=0.5*E(3)
      DET(5)=0.
      DET(6)=0.
      GO TO 71
   63 CONTINUE
      DO 64 J=1,6
      FAC=1.
      IF(J.GT.3)FAC=0.5
      DET(J)=FAC*DE(J)/SPLIT
      ET(J)=FAC*E(J)
   64 CONTINUE
   71 CONTINUE
C*****COMPUTE TEMPERATURE DEPENDENT MATERIAL CONSTANTS
      DEGM=DEG+0.5*DDEG
      CALL HYPCON(INDEP,NONISO,DEGM,
     1 EE,ANU,AK1,AK2,ANIN,AM,AN1,AN2,AN3,AN4,AN5,AN6,AN7,
     2 OMEGO,AKIND,SIINF,DN1DT,DN2DT,DOMDT,
     3 AN,ALAM,AMU,C1D,C2,C3,C4,C5)
      DEGM=DEG
      CALL HYPCON(INDEP,NONISO,DEGM,
     1 EE0,ANU0,AK10,AK20,ANIN0,AM0,AN10,AN20,AN30,AN40,AN50,AN60,AN70,
     2 OMEGO0,AKIND0,SIINF0,DN1DT0,DN2DT0,DOMDT0,
     3 ANT0,ALAM0,AMU0,C10,C20,C30,C40,C50)
      DEGM=DEG+DDEG
      CALL HYPCON(INDEP,NONISO,DEGM,
     1 EE1,ANU1,AK11,AK21,ANIN1,AM1,AN11,AN21,AN31,AN41,AN51,AN61,AN71,
     2 OMEGO1,AKIND1,SIINF1,DN1DT1,DN2DT1,DOMDT1,
     3 AN1,ALAM1,AMU1,C11,C21,C31,C41,C51)
C*****SET INITIAL VALUES OF EQUILIBRIUM STRESS
      DENOM=SINV(C(1).C(2),C(3),C(4),C(5),C(6))
      DENOM=DENOM+1.E-30
      AB(1)=-OMEGO+2.*OMEGO*(C(1)*C(1)+C(4)*C(4)+C(6)*C(6)
     1+1.E-30)/DENOM
      AB(2)=-OMEGO+2.*OMEGO*(C(4)*C(4)+C(2)*C(2)+C(5)*C(5)
     1+1.E-30)/DENOM
      AB(3)=-OMEGO+2.*OMEGO*(C(6)*C(6)+C(5)*C(5)+C(3)*C(3)+
     11.E-30)/DENOM
      AB(4)=2.*OMEGO*(C(1)*C(4)+C(2)*C(4)+C(5)*C(6)+1.E-30)/
     1DENOM
      AB(5)=2.*OMEGO*(C(4)*C(6)+C(2)*C(5)+C(3)*C(5)+1.E-30)/
     1DENOM
      AB(6)=2.*OMEGO*(C(1)*C(6)+C(4)*C(5)+C(3)*C(6)+1.E-30)/
     1DENOM
```

```
      ABSUM=AB(1)+AB(2)+AB(3)
      DO 7124 J=1,6
      ALPHA=1.
      IF(J.GT.3)ALPHA=0.
      OMEGI(J)=AB(J)-ALPHA*ABSUM/3.
 7124 CONTINUE
C*****COMPUTE DRAG STRESS
      AK=AK1-AK2*EXP(-AN7*R)
C*****COMPUTE INELASTIC STRAIN SUBINCREMENTS
      DO 67 J=1,6
      OV(J)=1.5*DEV(J)-OMEG(J)
   67 CONTINUE
      ARG1=SINV(OV(1),OV(2),OV(3),OV(4),OV(5),OV(6))
      ARG1=SQRT(ARG1)
      IF(ARG1.LE.1.E-10)ARG1=1.E-10
      ARG2=(ARG1/AK)**AN
      FAC=(ARG2/ARG1)*DT
      DO 302 J=1,6
      DC(J)=FAC*(1.5*DEV(J)-OMEG(J))
  302 CONTINUE
C****ADD TIME INDEPENDENT PART
      IF (INDEP .EQ. 0) GOTO68
      DAJ2=1.-AKIND*.666667*ARG1**2/(SIINF/AK1*AK)**2
      DWORK=0.
      DO 6801 J=1,6
 6801 DWORK=DWORK+SIG(J)*DET(J)*FLOAT(1+J/4)
      IF (DWORK .LT. 0) DWORK=0
      FACTOR=(1.-AKIND)*DWORK/(SIINF/AK1*AK)**2/DAJ2
      DO 6803 J=1,6
 6803 DC(J)=FACTOR*OV(J)+DC(J)
C*****COMPUTE EQUILIBRIUM STRESS SUBINCREMENTS
 68   OM2=SINV(OMEG(1),OMEG(2),OMEG(3),OMEG(4),OMEG(5),OMEG(6))
      OM2=SQRT(OM2)
      DR=SINV(DC(1),DC(2),DC(3),DC(4),DC(5),DC(6))
      DR=SQRT(DR)
      DG=(AN3+AN4*EXP(-AN5*R))*DR+AN6*DT*OM2**(AM-1.)
      DO 303 J=1,6
      DOMEG(J)=(AN1+AN2)*DC(J)-DG*(OMEG(J)-OMEGI(J)-AN1*C(J))
      IF (NONISO .EQ. 0) GOTO303
      DOMEG(J)=DOMEG(J)+(OMEG(J)-OMEGI(J)-AN1*DC(J))*DN2DT*DDEG
     1+DN1DT*DC(J)*DDEG
      DDENOM=(C(1)*DC(1)+C(2)*DC(2)+C(3)*DC(3)+
     1 2.*(C(4)*DC(4)+C(5)*DC(5)*C(6)*DC(6)))
      DOM=DOMDT*DDEG
      DOM1=DOM-2.*OMEGO*DDENOM
      DENOM=SINV(C(1),C(2),C(3),C(4),C(5),C(6))
      DENOM=DENOM+1.E-30
      DAB(1)=-DOM+2.*DOM1*(C(1)*C(1)+C(4)*C(4)+C(6)*C(6)
     1+1.E-30)/DENOM
      DAB(2)=-DOM+2.*DOM1*(C(4)*C(4)+C(2)*C(2)+C(5)*C(5)
     1+1.E-30)/DENOM
      DAB(3)=-DOM+2.*DOM1*(C(6)*C(6)+C(5)*C(5)+C(3)*C(3)+
     11.E-30)/DENOM
      DAB(4)=2.*DOM1*(C(1)*C(4)+C(2)*C(4)+C(5)*C(6)+1.E-30)/
     1DENOM
      DAB(5)=2.*DOM1*(C(4)*C(6)+C(2)*C(5)+C(3)*C(5)+1.E-30)/
     1DENOM
      DAB(6)=2.*DOM1*(C(1)*C(6)+C(4)*C(5)+C(3)*C(6)+1.E-30)/
     1DENOM
      DAB(1)=DAB(1)+2.*OMEGO*(DC(1)*C(1)+DC(4)*C(4)+DC(6)*C(6)
     1+1.E-30)/DENOM
      DAB(2)=DAB(2)+2.*OMEGO*(DC(4)*C(4)+DC(2)*C(2)+DC(5)*C(5)
     1+1.E-30)/DENOM
      DAB(3)=DAB(3)+2.*OMEGO*(DC(6)*C(6)+DC(5)*C(5)+DC(3)*C(3)+
     11.E-30)/DENOM
      DAB(4)=DAB(4)+2.*OMEGO*(DC(1)*C(4)+DC(2)*C(4)+DC(5)*C(6)+1.E-30)/
     1DENOM
      DAB(5)=DAB(5)+2.*OMEGO*(DC(4)*C(6)+DC(2)*C(5)+DC(3)*C(5)+1.E-30)/
     1DENOM
      DAB(6)=DAB(6)+2.*OMEGO*(DC(1)*C(6)+DC(4)*C(5)+DC(3)*C(6)+1.E-30)/
     1DENOM
      DAB(1)=DAB(1)+2.*OMEGO*(C(1)*DC(1)+C(4)*DC(4)+C(6)*DC(6)
     1+1.E-30)/DENOM
      DAB(2)=DAB(2)+2.*OMEGO*(C(4)*DC(4)+C(2)*DC(2)+C(5)*DC(5)
```

```
     1+1.E-30)/DENOM
      DAB(3)=DAB(3)+2.*OMEGO*(C(6)*DC(6)+C(5)*DC(5)+C(3)*DC(3)+
     11.E-30)/DENOM
      DAB(4)=DAB(4)+2.*OMEGO*(C(1)*DC(4)+C(2)*DC(4)+C(5)*DC(6)+1.E-30)/
     1DENOM
      DAB(5)=DAB(5)+2.*OMEGO*(C(4)*DC(6)+C(2)*DC(5)+C(3)*DC(5)+1.E-30)/
     1DENOM
      DAB(6)=DAB(6)+2.*OMEGO*(C(1)*DC(6)+C(4)*DC(5)+C(3)*DC(6)+1.E-30)/
     1DENOM
  303 CONTINUE
C*****COMPUTE STRESS SUBINCREMENTS
      IF(KELTYP.EQ.2)DET(3)=(2.*AMU*DC(3)-ALAM*(DET(1)+DET(2)))/(ALAM+2.
     1*AMU)
      DVOLO=0.
      DVOL1=0.
      DO 809 J=1,6
      ET1(J)=ET(J)+DET(J)
      C1(J)=C(J)+DC(J)
      IF (J .GT. 3) GOTO809
      DVOLO=DVOLO+ET(J)
      DVOL1=DVOL1+ET1(J)
  809 CONTINUE
      DO 810 J=1,6
      FAC=FLOAT(1-J/4)
      SO=ALAMO*DVOLO*FAC+2.*AMUO*(ET(J)-C(J))
      S1=ALAM1*DVOL1*FAC+2.*AMU1*(ET1(J)-C1(J))
      DSIG(J)=S1-SO
      IF (KELTYP .NE. 2) GOTO810
      DSIGIN=FAC*2.*AMU*ALAM*DC(3)/(ALAM+2.*AMU)-2.*DC(J)*AMU
      DSIG(J)=DSIGIN+(ALAM+2.*AMU)*FAC*(DVOL1-DVOLO)+2.*AMU*DET(J)
  810 CONTINUE
C     IF SELF ADAPTIVE INTEGRATION IS USED THEN CALCULATE STRAIN
C     STEP, MAKE APPROPRIATE CHANGES TO NSPLIT AND GO TO
C     CORRESPONDING PROGRAM STEP
      IF (KEY .EQ. 1)GOTO410
      ERRORO=SINV(DSIG(1),DSIG(2),DSIG(3),DSIG(4),DSIG(5)
     1,DSIG(6))
      ERRORO=SQRT(ERRORO)/EE+DR
      IF (ERRORO .LT. ERROR2) NSPLIT=(NSPLIT-1)/2+1
      IF (ERRORO .LT. ERROR1) GOTO410
      NSPLIT=2*NSPLIT
      GOTO5
C*****UPDATE SUBINCREMENT VARIABLES
  410 DEG=DEG+DDEG
      IF (NSPLIT .GT. MXSPLT) NSPLIT=MXSPLT-1
      R=R+DR
      DO 113 J=1,6
      OMEG(J)=OMEG(J)+DOMEG(J)
      SIG(J)=SIG(J)+DSIG(J)
      C(J)=C1(J)
      ET(J)=ET1(J)
      SUMSIG(J)=SUMSIG(J)+DSIG(J)
  113 CONTINUE
      PRESS=(SIG(1)+SIG(2)+SIG(3))/3.
      DO 114 J=1,6
      ALPHA=1.
      IF(J.GT.3)ALPHA=0.
      DEV(J)=SIG(J)-ALPHA*PRESS
  114 CONTINUE
C*****END OF SUBINCREMENT LOOP
      T=T+DT
      GOTO5
C*****PUT ELASTICITY MATRIX IN D AND INELASTIC STRESS INCREMENT IN G
  420 GO TO(814,815,816),KELTYP
  814 CONTINUE
      DO 817 J=1,4
      DO 817 K=1,4
      D(J,K)=0.
  817 CONTINUE
      DO 818 J=1,3
      DO 818 K=1,3
      ALPHA=0.
      IF(J.EQ.K) ALPHA=1.
      D(J,K)=C5M+ALPHA*C3M
```

```
  818 CONTINUE
      D(4,4)=C4M
      GO TO 903
  815 CONTINUE
      D(1,1)=C2M
      D(1,2)=C1M
      D(2,1)=C1M
      D(1,3)=0.
      D(3,1)=0.
      D(2,2)=C2M
      D(2,3)=0.
      D(3,2)=0.
      D(3,3)=C4M
      GO TO 903
  816 CONTINUE
      DO 819 J=1,6
      DO 819 K=1,6
      D(J,K)=0.
  819 CONTINUE
      DO 820 J=1,3
      DO 820 K=1,3
      ALPHA=0.
      IF(J.EQ.K) ALPHA=1.
      D(J,K)=C5M+ALPHA*C3M
  820 CONTINUE
      D(4,4)=C4M
      D(5,5)=C4M
      D(6,6)=C4M
  903 CONTINUE
      DO 821 J=1,NGENS
      G(J)=SUMSIG(J)
      IF (KELTYP .EQ. 2 .AND. J .EQ. 3) G(3)=SUMSIG(4)
      DO 821 K=1,NGENS
 821  G(J)=G(J)-D(J,K)*DE(K)
C*****COMPUTE STRESS AT END OF MARC INCREMENT
      DO 822 J=1,NGENS
      SUM=0.
      DO 823 K=1,NGENS
      SUM=SUM+D(J,K)*DE(K)
  823 CONTINUE
      DS(J)=SUM+G(J)
  822 CONTINUE
C*****PUT STATE VARIABLE INCREMENTS IN TEMP ARRAY FOR NEXT MARC INCREMENT
      DTEMP(3)=R-TEMP(3)
      TEMP(16)=NSPLIT
      DO 923 KA=1,6
      J=KA+3
      DTEMP(J)=OMEG(KA)-TEMP(J)
      DTEMP(J+6)=C(KA)-TEMP(J+6)
  923 CONTINUE
      IF(IPR.EQ.0) GO TO 12
      IF(NELPR.NE.N) GO TO 12
      IF (NN.NE.NPRIN) GO TO 12
      WRITE(6,20) INC
   20 FORMAT(11H INCREMENT ,I5)
      IF(NQ.EQ.0) WRITE(6,23) NQQ
      IF(NQ.GT.0) WRITE(6,39) NCYCLE
   23 FORMAT(55H VALUES OF PARAMETERS DURING SOLUTION OF RECYCLE NUMBER,
     1I5)
   39 FORMAT(55H VALUES OF PARAMETERS DURING ASSEMBLY OF RECYCLE NUMBER,
     1I5)
      WRITE(6,29)
   29 FORMAT(18H STRAIN INCREMENTS)
      WRITE(6,30) (DE(J),J=1,NGENS)
   30 FORMAT(1P6E15.6)
      WRITE(6,31)
   31 FORMAT(18H STRESS INCREMENTS)
      WRITE(6,30) (DS(J),J=1,NGENS)
   12 RETURN
C     DEBUG SUBTRACE,UNIT(25),SUBCHK,INIT
C     AT 1234
      END
```

APPENDIX 2. SUBROUTINE HYPCON

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OF POOR QUALITY

```
      SUBROUTINE HYPCON(INDEP,NONISO,DEGM,
     1 EE,ANU,AK1,AK2,ANIN,AM,AN1,AN2,AN3,AN4,AN5,AN6,AN7,
     2 OMEGO,AKIND,SIINF,DN1DT,DN2DT,DOMDT,
     3 AN,ALAM,AMU,C1,C2,C3,C4,C5)
C     THIS SUBROUTINE IS CALLED BY HYPELA TO CALCULATE ALL OF THE
C     TEMPERATURE DEPENDENT MATERIAL CONSTANTS
      DIMENSION TABT(6),EET(6),ANUT(6),AK1T(6),ANINT(6),AMT(6),AN1T(6)
      DIMENSION AN2T(6),AN3T(6),AN4T(6),AN5T(6),AN6T(6),AN7T(6),AK2T(6)
      DIMENSION OMEGOT(6)
      DIMENSION AKINDT(6),SIINFT(6)
      DATA TABT/800.,1000.,1200.,1400.,1600.,1800./
      DATA EET/26.E6,24.E6,24.E6,22.6E6,18.6E6,13.2E6/
      DATA ANUT/0.322,0.328,0.334,0.339,0.345,0.351/
      DATA AK1T/50931.,75631.,95631.,110696.,91505.,59292./
      DATA AK2T/0.,0.,0.,0.,0.,0./
      DATA ANINT/.059,.059,.079,.1497,.195,.223/
      DATA AMT/1.158,1.158,1.158,1.158,1.158,1.158/
      DATA AN1T/0.,0.,0.,0.,0.,0./
      DATA AN2T/1.E7,1.9E7,1.5E7,2.E7,5.E6,1.E6/
      DATA AN3T/250.,320.,781.2,1178.6,672.6,312.5/
      DATA AN4T/0.,0.,0.,0.,0.,0./
      DATA AN5T/0.,0.,0.,0.,0.,0./
      DATA AN6T/0.,0.,0.,0.,8.977E-4,2.733E-3/
      DATA AN7T/0.,0.,0.,0.,0.,0./
      DATA OMEGOT/0.,0.,-2000.,-2000.,-1434.,-1200./
      DATA AKINDT/0.,0.,0.,0.,0.,0./
      DATA SIINFT/48.E3,48.E3,60.E3,1.E10,1.E10,1.E10/
 1234 NTP=6
      NTPM1=NTP-1
      TDIF=TABT(2)-TABT(1)
      L1=DEGM
      L2=TABT(1)-TDIF
      L3=TDIF
      IT=(L1-L2)/L3
      IF(IT.LT.1)IT=1
      IF(IT.GT.NTPM1)IT=NTPM1
      FAC=(DEGM-TABT(IT))/TDIF
      EE=(EET(IT+1)-EET(IT))*FAC+EET(IT)
      ANU=(ANUT(IT+1)-ANUT(IT))*FAC+ANUT(IT)
      AK1=(AK1T(IT+1)-AK1T(IT))*FAC+AK1T(IT)
      AK2=(AK2T(IT+1)-AK2T(IT))*FAC+AK2T(IT)
      ANIN=(ANINT(IT+1)-ANINT(IT))*FAC+ANINT(IT)
      AM=(AMT(IT+1)-AMT(IT))*FAC+AMT(IT)
      AN1=(AN1T(IT+1)-AN1T(IT))*FAC+AN1T(IT)
      AN2=(AN2T(IT+1)-AN2T(IT))*FAC+AN2T(IT)
      AN3=(AN3T(IT+1)-AN3T(IT))*FAC+AN3T(IT)
      AN4=(AN4T(IT+1)-AN4T(IT))*FAC+AN4T(IT)
      AN5=(AN5T(IT+1)-AN5T(IT))*FAC+AN5T(IT)
      AN6=(AN6T(IT+1)-AN6T(IT))*FAC+AN6T(IT)
      AN7=(AN7T(IT+1)-AN7T(IT))*FAC+AN7T(IT)
      OMEGO=(OMEGOT(IT+1)-OMEGOT(IT))*FAC+OMEGOT(IT)
      IF (INDEP .EQ. 0) GOTO65
      AKIND=(AKINDT(IT+1)-AKINDT(IT))*FAC+AKINDT(IT)
      SIINF=(SIINFT(IT+1)-SIINFT(IT))*FAC+SIINFT(IT)
   65 IF (NONISO .EQ. 0) GOTO73
      DN1DT=(AN1T(IT+1)-AN1T(IT))/TDIF/(AN1+1.E-6)
      DN2DT=(AN2T(IT+1)-AN2T(IT))/TDIF/(AN2+1.E-6)
      DOMDT=(OMEGOT(IT+1)-OMEGOT(IT))/TDIF/(OMEGO+1.E-6)
   73 CONTINUE
      AN=1./ANIN
      ALAM=EE*ANU/((1.-2.*ANU)*(1.+ANU))
      AMU=(1.-2.*ANU)*ALAM/(2.*ANU)
      C1=2.*AMU*ALAM/(ALAM+2.*AMU)
      C2=4.*AMU*(ALAM+AMU)/(ALAM+2.*AMU)
      C3=2.*AMU
      C4=AMU
      C5=ALAM
      RETURN
```

```
C     DEBUG SUBTRACE,UNIT(25),SUBCHK,INIT
C     AT 1234
      END
```

APPENDIX 3. SUBROUTINE THRUH


```
  101 CALL GMPRD(S,E1,DSEG,1,NGENS,1)
      CALL SCLA(B,0.,NGENS,NGENS,0)
      CALL SCLA(GF,0.,NGENS,1,0)
C     USER SUPPLIED HYPOELASTIC CONSTITUTIVE THEORY
C * * * * *
      CALL HYPELA(B,GF,EELAS,E1,S,DT,DTDL,NGENS,M,NNN,KC,MAT,NDI,NSHEAR)
      LOADUQ=1
C     TOTAL ELASTIC STRAINS
C * * * * *
      CALL GMADD(EELAS,E1,EELAS,NGENS,1)
C     INCREMENTAL STRESS COMPONENTS
C * * * * *
```

APPENDIX 4. SUBROUTINE INCDT1


```
⋮
 16   CONTINUE
  161 CONTINUE
C
C**** BOUNDARY CHANGE
      IASMBL=1
      READ(5,103)CARD
      CALL INTAC(CARD,ICARD,3,JBAD)
      IF(JBAD.EQ.1)GO TO 110
      NEWBC=ICARD(1)
      IFLAG=ICARD(2)
      IF(IFLAG.EQ.1) WRITE(6,1613)
 1613 FORMAT(63HOFOLLOWING INFORMATION APPLIES TO HARMONIC RESPONSE CALC
⋮
```

```
      •
      •
      •
  399 CONTINUE
      LA1=MMS4+ISIGXX
      LA2=LMS1+IGSIG
      IF(IHRESP.EQ.1)LA2=IGSIG1
      IF(ISHELL.EQ.1)GO TO 617
      IF(JTYPE.EQ.52)GO TO 620
      IF(IHRESP.EQ.1) GO TO 618
      DSEGAA=ABS(DSEG)
      DSEGEA=DSEGE
      DSEGA=DSEG
      IF(ICREEP.EQ.1.OR.ITHERM.GT.0)CALL TPSMA(VARS(IB1),VARS(IECRP1),
     1VARS(IFCRP),1.,NGEN1,NGEN1,1)
      IF(IPELA.EQ.1)
     *CALL GMSUB(VARS(IFCRP),VARS(IGF),VARS(IFCRP),NGEN1,1)
      IF(IHERED.EQ.0) GO TO 310
      IF(MATV.EQ.0.OR.IVSCFN.NE.2) GO TO 310
      IVS=IVNSER+MATV-1
      NVSER=INTS(IVS)
      IF(NVSER.EQ.0) GO TO 310
      IVD=IVDSIZ+MATV-1
      NVDSIZ=INTS(IVD)
      CALL GMADD(VARS(IFCRP),VARS(IGFV2),VARS(IFCRP),NVDSIZ,1)
  310 CONTINUE
  618 CONTINUE
      •
      •
      •
```

APPENDIX 6. DATA INPUT FOR CLOSED SYMMETRIC TMF LOOP

```
TITLE        THERMOMECHANICAL LOOP NO. 1 WITH FUNCTIONAL THEORY
SIZING           15000     4     9     9     2    10
POST           2
ALL POINTS
INPUT TAPE     1
HYPOELAS
STATE VARS    16
NC LOADCOR     1
RESTART
END
MESH2D
BLOCKS
     1    4   10    1    1    9         6
DEFINE
     1    2    2    1    2    3    4
BOUNDARY
     1         1.
     2         1.         1.
     3         0.         1.
     4
CONSTRAINT
     2
     1    3    1
     1    4    2
MERGE
.0005
GENERATE
CONNECTIVITY
          1
COORDINATES
               1
BOUNDARY CONDITIONS
     0    1    1
BOUNDARY CONDITIONS
1,
1,3,1,1,1.E-8
THERMAL LOADS
1,
0.,1.E-8

PROPERTY
     1
     26.0E6         .322              0.E-5
     1    4
POST
     2   16   16
     1
    11
PRINT CHOICE
               1
     1
```

```
CONTROL
49,15,1,0
          .05
RESTART
1,1,0,8,8
INITIAL STATE
1,1,1
1,4,1,4
800.
END OPTION
BOUNDARY CHANGE
3,
7,1,1,  .001239
8,2,1,  .001239
9,3,1,  .001239
THERMAL LOADS
1,
 3.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000032
8,2,1, -.000032
9,3,1, -.000032
THERMAL LOADS
1,
 10.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000053
8,2,1, -.000053
9,3,1, -.000053
THERMAL LOADS
1,
 16.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000072
8,2,1, -.000072
9,3,1, -.000072
THERMAL LOADS
1,
 23.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000091
8,2,1, -.000091
9,3,1, -.000091
THERMAL LOADS
1,
 29.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000108
8,2,1, -.000108
9,3,1, -.000108
THERMAL LOADS
1,
 34.5.1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000123
8,2,1, -.000123
9,3,1, -.000123
THERMAL LOADS
1,
 39.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000136
8,2,1, -.000136
9,3,1, -.000136
THERMAL LOADS
1,
 43.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000147
8,2,1, -.000147
9,3,1, -.000147
THERMAL LOADS
1,
 46.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000155
8,2,1, -.000155
9,3,1, -.000155
THERMAL LOADS
1,
 49.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000160
8,2,1, -.000160
9,3,1, -.000160
THERMAL LOADS
1,
 51.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000163
8,2,1, -.000163
9,3,1, -.000163
THERMAL LOADS
1,
 52.2.1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000163
8,2,1, -.000163
9,3,1, -.000163
THERMAL LOADS
1,
 52.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
```

```
7,1,1, -.000160
8,2,1, -.000160
9,3,1, -.000160
THERMAL LOADS
1,
51.3,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000155
8,2,1, -.000155
9,3,1, -.000155
THERMAL LOADS
1,
49.5,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000147
8,2,1, -.000147
9,3,1, -.000147
THERMAL LOADS
1,
46.9,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000136
8,2,1, -.000136
9,3,1, -.000136
THERMAL LOADS
1,
43.5,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000123
8,2,1, -.000123
9,3,1, -.000123
THERMAL LOADS
1,
39.3,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000108
8,2,1, -.000108
9,3,1, -.000108
THERMAL LOADS
1,
34.5,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000091
8,2,1, -.000091
9,3,1, -.000091
THERMAL LOADS
1,
29.1,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000072
8,2,1, -.000072
9,3,1, -.000072
THERMAL LOADS
1,
23.1,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000053
8,2,1, -.000053
9,3,1, -.000053
THERMAL LOADS
1,
16.8,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000032
8,2,1, -.000032
9,3,1, -.000032
THERMAL LOADS
1,
10.2,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000011
8,2,1, -.000011
9,3,1, -.000011
THERMAL LOADS
1,
3.4,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000011
8,2,1,  .000011
9,3,1,  .000011
THERMAL LOADS
1,
-3.4,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000032
8,2,1,  .000032
9,3,1,  .000032
THERMAL LOADS
1,
-10.2,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000053
8,2,1,  .000053
9,3,1,  .000053
THERMAL LOADS
1,
-16.8,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000072
8,2,1,  .000072
9,3,1,  .000072
THERMAL LOADS
1,
```

```
-23.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000091
8,2,1,   .000091
9,3,1,   .000091
THERMAL LOADS
1,
-29.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000108
8,2,1,   .000108
9,3,1,   .000108
THERMAL LOADS
1,
-34.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000123
8,2,1,   .000123
9,3,1,   .000123
THERMAL LOADS
1,
-39.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000136
8,2,1,   .000136
9,3,1,   .000136
THERMAL LOADS
1,
-43.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000147
8,2,1,   .000147
9,3,1,   .000147
THERMAL LOADS
1,
-46.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000155
8,2,1,   .000155
9,3,1,   .000155
THERMAL LOADS
1,
-49.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000160
8,2,1,   .000160
9,3,1,   .000160
THERMAL LOADS
1,
-51.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000163
8,2,1,   .000163
9,3,1,   .000163
THERMAL LOADS
1,
-52.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000163
8,2,1,   .000163
9,3,1,   .000163
THERMAL LOADS
1,
-52.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000160
8,2,1,   .000160
9,3,1,   .000160
THERMAL LOADS
1,
-51.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000155
8,2,1,   .000155
9,3,1,   .000155
THERMAL LOADS
1,
-49.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000147
8,2,1,   .000147
9,3,1,   .000147
THERMAL LOADS
1,
-46.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000136
8,2,1,   .000136
9,3,1,   .000136
THERMAL LOADS
1,
-43.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000123
8,2,1,   .000123
9,3,1,   .000123
THERMAL LOADS
1,
-39.3,1.250000

CONTINUE
BOUNDARY CHANGE
```

```
3,
7,1,1,  .000108
8,2,1,  .000108
9,3,1,  .000108
THERMAL LOADS
1,
-34.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000091
8,2,1,  .000091
9,3,1,  .000091
THERMAL LOADS
1,
-29.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000072
8,2,1,  .000072
9,3,1,  .000072
THERMAL LOADS
1,
-23.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000053
8,2,1,  .000053
9,3,1,  .000053
THERMAL LOADS
1,
-16.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000032
8,2,1,  .000032
9,3,1,  .000032
THERMAL LOADS
1,
-10.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000011
8,2,1,  .000011
9,3,1,  .000011
THERMAL LOADS
1,
-3.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000011
8,2,1, -.000011
9,3,1, -.000011
THERMAL LOADS
1,
3.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000032
8,2,1, -.000032
9,3,1, -.000032
THERMAL LOADS
1,
10.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000053
8,2,1, -.000053
9,3,1, -.000053
THERMAL LOADS
1,
16.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000072
8,2,1, -.000072
9,3,1, -.000072
THERMAL LOADS
1,
23.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000091
8,2,1, -.000091
9,3,1, -.000091
THERMAL LOADS
1,
29.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000108
8,2,1, -.000108
9,3,1, -.000108
THERMAL LOADS
1,
34.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000123
8,2,1, -.000123
9,3,1, -.000123
THERMAL LOADS
1,
39.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000136
8,2,1, -.000136
9,3,1, -.000136
THERMAL LOADS
1,
43.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000147
8,2,1, -.000147
9,3,1, -.000147
THERMAL LOADS
1,
```

```
 46.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000155
8,2,1, -.000155
9,3,1, -.000155
THERMAL LOADS
1,
 49.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000160
8,2,1, -.000160
9,3,1, -.000160
THERMAL LOADS
1,
 51.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000163
8,2,1, -.000163
9,3,1, -.000163
THERMAL LOADS
1,
 52.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000163
8,2,1, -.000163
9,3,1, -.000163
THERMAL LOADS
1,
 52.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000160
8,2,1, -.000160
9,3,1, -.000160
THERMAL LOADS
1,
 51.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000155
8,2,1, -.000155
9,3,1, -.000155
THERMAL LOADS
1,
 49.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000147
8,2,1, -.000147
9,3,1, -.000147
THERMAL LOADS
1,
 46.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000136
8,2,1, -.000136
9,3,1, -.000136
THERMAL LOADS
1,
 43.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000123
8,2,1, -.000123
9,3,1, -.000123
THERMAL LOADS
1,
 39.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000108
8,2,1, -.000108
9,3,1, -.000108
THERMAL LOADS
1,
 34.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000091
8,2,1, -.000091
9,3,1, -.000091
THERMAL LOADS
1,
 29.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000072
8,2,1, -.000072
9,3,1, -.000072
THERMAL LOADS
1,
 23.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000053
8,2,1, -.000053
9,3,1, -.000053
THERMAL LOADS
1,
 16.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000032
8,2,1, -.000032
9,3,1, -.000032
THERMAL LOADS
1,
 10.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
```

```
7,1,1, -.000011
8,2,1, -.000011
9,3,1, -.000011
THERMAL LOADS
1,
 3.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000011
8,2,1,  .000011
9,3,1,  .000011
THERMAL LOADS
1,
-3.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000032
8,2,1,  .000032
9,3,1,  .000032
THERMAL LOADS
1,
-10.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000053
8,2,1,  .000053
9,3,1,  .000053
THERMAL LOADS
1,
-16.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000072
8,2,1,  .000072
9,3,1,  .000072
THERMAL LOADS
1,
-23.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000091
8,2,1,  .000091
9,3,1,  .000091
THERMAL LOADS
1,
-29.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000108
8,2,1,  .000108
9,3,1,  .000108
THERMAL LOADS
1,
-34.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000123
8,2,1,  .000123
9,3,1,  .000123
THERMAL LOADS
1,
-39.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000136
8,2,1,  .000136
9,3,1,  .000136
THERMAL LOADS
1,
-43.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000147
8,2,1,  .000147
9,3,1,  .000147
THERMAL LOADS
1,
-46.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000155
8,2,1,  .000155
9,3,1,  .000155
THERMAL LOADS
1,
-49.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000160
8,2,1,  .000160
9,3,1,  .000160
THERMAL LOADS
1,
-51.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000163
8,2,1,  .000163
9,3,1,  .000163
THERMAL LOADS
1,
-52.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000163
8,2,1,  .000163
9,3,1,  .000163
THERMAL LOADS
1,
-52.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000160
8,2,1,  .000160
9,3,1,  .000160
THERMAL LOADS
```

```
1,
-51.3,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000155
8,2,1,   .000155
9,3,1,   .000155
THERMAL LOADS
1,
-49.5,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000147
8,2,1,   .000147
9,3,1,   .000147
THERMAL LOADS
1,
-46.9,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000136
8,2,1,   .000136
9,3,1,   .000136
THERMAL LOADS
1,
-43.5,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000123
8,2,1,   .000123
9,3,1,   .000123
THERMAL LOADS
1,
-39.3,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000108
8,2,1,   .000108
9,3,1,   .000108
THERMAL LOADS
1,
-34.5,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000091
8,2,1,   .000091
9,3,1,   .000091
THERMAL LOADS
1,
-29.1,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000072
8,2,1,   .000072
9,3,1,   .000072
THERMAL LOADS
1,
-23.1,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000053
8,2,1,   .000053
9,3,1,   .000053
THERMAL LOADS
1,
-16.8,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000032
8,2,1,   .000032
9,3,1,   .000032
THERMAL LOADS
1,
-10.2,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000011
8,2,1,   .000011
9,3,1,   .000011
THERMAL LOADS
1,
-3.4,1.250000
CONTINUE
```

APPENDIX 7. DATA INPUT FOR OPEN SYMMETRIC TMF LOOP

```
TITLE       THERMOMECHANICAL LOOP NO. 2 WITH FUNCTIONAL THEORY
SIZING          15000    4    9    9    2   10
POST           2
ALL POINTS
INPUT TAPE     1
HYPOELAS
STATE VARS    16
NO LOADCOR     1
RESTART
END
MESH2D
BLOCKS
    1    4   10    1    1    9         6
DEFINE
    1    2    2    1    2    3    4
BOUNDARY
    1         1.
    2         1.        1.
    3         0.        1.
    4
CONSTRAINT
    2
    1    3    1
    1    4    2
MERGE
.0005
GENERATE
CONNECTIVITY
         1
COORDINATES
              1
BOUNDARY CONDITIONS
    0    1    1
BOUNDARY CONDITIONS
1,
1,3,1,1,1.E-8
THERMAL LOADS
1,
0.,1.E-8

PROPERTY
    1
    26.0E6        .322              0.E-5
    1    4
POST
    2   16   16
    1
   11
PRINT CHOICE
              1
```

```
       1
CONTROL
49,15,1,0
           .05
RESTART
1,1,0,8,8
INITIAL STATE
1,1,1
1,4,1,4
820.
END OPTION
BOUNDARY CHANGE
3,
7,1,1,  .000150
8,2,1,  .000150
9,3,1,  .000150
THERMAL LOADS
1,
 19.0,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000065
8,2,1, -.000065
9,3,1, -.000065
THERMAL LOADS
1,
 25.6,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000088
8,2,1, -.000088
9,3,1, -.000088
THERMAL LOADS
1,
 31.3,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000108
8,2,1, -.000108
9,3,1, -.000108
THERMAL LOADS
1,
 36.5,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000126
8,2,1, -.000126
9,3,1, -.000126
THERMAL LOADS
1,
 41.1,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000142
8,2,1, -.000142
9,3,1, -.000142
THERMAL LOADS
1,
 45.0,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000155
8,2,1, -.000155
9,3,1, -.000155
THERMAL LOADS
1,
 48.1,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000166
8,2,1, -.000166
9,3,1, -.000166
THERMAL LOADS
1,
 50.4,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000174
8,2,1, -.000174
9,3,1, -.000174
THERMAL LOADS
1,
 51.8,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000179
8,2,1, -.000179
9,3,1, -.000179
```

```
THERMAL LOADS
1,
 52.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000180
8,2,1, -.000180
9,3,1, -.000180
THERMAL LOADS
1,
 52.0,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000179
8,2,1, -.000179
9,3,1, -.000179
THERMAL LOADS
1,
 50.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000175
8,2,1, -.000175
9,3,1, -.000175
THERMAL LOADS
1,
 48.6,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000243
8,2,1, -.000243
9,3,1, -.000243
THERMAL LOADS
1,
 45.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000034
8,2,1, -.000034
9,3,1, -.000034
THERMAL LOADS
1,
 41.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000031
8,2,1, -.000031
9,3,1, -.000031
THERMAL LOADS
1,
 37.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000028
8,2,1, -.000028
9,3,1, -.000028
THERMAL LOADS
1,
 32.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000024
8,2,1, -.000024
9,3,1, -.000024
THERMAL LOADS
1,
 26.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000020
8,2,1, -.000020
9,3,1, -.000020
THERMAL LOADS
1,
 20.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000015
8,2,1, -.000015
9,3,1, -.000015
THERMAL LOADS
1,
 14.2,1.250000

CONTINUE
BOUNDARY CHANGE
```

```
3,
7,1,1, -.000011
8,2,1, -.000011
9,3,1, -.000011
THERMAL LOADS
1,
  7.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000108
8,2,1,  .000108
9,3,1,  .000108
THERMAL LOADS
1,
   .7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000063
8,2,1, -.000063
9,3,1, -.000063
THERMAL LOADS
1,
 -6.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000569
8,2,1,  .000569
9,3,1,  .000569
THERMAL LOADS
1,
-12.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .001229
8,2,1,  .001229
9,3,1,  .001229
THERMAL LOADS
1,
-19.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000086
8,2,1,  .000086
9,3,1,  .000086
THERMAL LOADS
1,
-25.6,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000114
8,2,1,  .000114
9,3,1,  .000114
THERMAL LOADS
1,
-31.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000139
8,2,1,  .000139
9,3,1,  .000139
THERMAL LOADS
1,
-36.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000162
8,2,1,  .000162
9,3,1,  .000162
THERMAL LOADS
1,
-41.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000183
8,2,1,  .000183
9,3,1,  .000183
THERMAL LOADS
1,
-45.0,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000200
8,2,1,  .000200
9,3,1,  .000200
THERMAL LOADS
1,
```

```
-48.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000214
8,2,1,  .000214
9,3,1,  .000214
THERMAL LOADS
1,
-50.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000224
8,2,1,  .000224
9,3,1,  .000224
THERMAL LOADS
1,
-51.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000230
8,2,1,  .000230
9,3,1,  .000230
THERMAL LOADS
1,
-52.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000247
8,2,1,  .000247
9,3,1,  .000247
THERMAL LOADS
1,
-52.0,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000048
8,2,1,  .000048
9,3,1,  .000048
THERMAL LOADS
1,
-50.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000047
8,2,1,  .000047
9,3,1,  .000047
THERMAL LOADS
1,
-48.6,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000045
8,2,1,  .000045
9,3,1,  .000045
THERMAL LOADS
1,
-45.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000043
8,2,1,  .000043
9,3,1,  .000043
THERMAL LOADS
1,
-41.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000039
8,2,1,  .000039
9,3,1,  .000039
THERMAL LOADS
1,
-37.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000035
8,2,1,  .000035
9,3,1,  .000035
THERMAL LOADS
1,
-32.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000030
```

```
8,2,1,  .000030
9,3,1,  .000030
THERMAL LOADS
1,
-26.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000025
8,2,1,  .000025
9,3,1,  .000025
THERMAL LOADS
1,
-20.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000019
8,2,1,  .000019
9,3,1,  .000019
THERMAL LOADS
1,
-14.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000013
8,2,1,  .000013
9,3,1,  .000013
THERMAL LOADS
1,
 -7.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000106
8,2,1, -.000106
9,3,1, -.000106
THERMAL LOADS
1,
  -.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000063
8,2,1,  .000063
9,3,1,  .000063
THERMAL LOADS
1,
  6.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000569
8,2,1, -.000569
9,3,1, -.000569
THERMAL LOADS
1,
 12.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.001229
8,2,1, -.001229
9,3,1, -.001229
THERMAL LOADS
1,
 19.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000067
8,2,1, -.000067
9,3,1, -.000067
THERMAL LOADS
1,
 25.6,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000088
8,2,1, -.000088
9,3,1, -.000088
THERMAL LOADS
1,
 31.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000108
8,2,1, -.000108
9,3,1, -.000108
THERMAL LOADS
1,
 36.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000126
8,2,1, -.000126
9,3,1, -.000126
```

```
THERMAL LOADS
1,
 41.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000142
8,2,1, -.000142
9,3,1, -.000142
THERMAL LOADS
1,
 45.0,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000155
8,2,1, -.000155
9,3,1, -.000155
THERMAL LOADS
1,
 48.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000166
8,2,1, -.000166
9,3,1, -.000166
THERMAL LOADS
1,
 50.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000174
8,2,1, -.000174
9,3,1, -.000174
THERMAL LOADS
1,
 51.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000179
8,2,1, -.000179
9,3,1, -.000179
THERMAL LOADS
1,
 52.3,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000180
8,2,1, -.000180
9,3,1, -.000180
THERMAL LOADS
1,
 52.0,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000179
8,2,1, -.000179
9,3,1, -.000179
THERMAL LOADS
1,
 50.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000175
8,2,1, -.000175
9,3,1, -.000175
THERMAL LOADS
1,
 48.6,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000243
8,2,1, -.000243
9,3,1, -.000243
THERMAL LOADS
1,
 45.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000034
8,2,1, -.000034
9,3,1, -.000034
THERMAL LOADS
1,
 41.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000031
```

```
8,2,1, -.000031
9,3,1, -.000031
THERMAL LOADS
1,
 37.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000028
8,2,1, -.000028
9,3,1, -.000028
THERMAL LOADS
1,
 32.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000024
8,2,1, -.000024
9,3,1, -.000024
THERMAL LOADS
1,
 26.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000020
8,2,1, -.000020
9,3,1, -.000020
THERMAL LOADS
1,
 20.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000015
8,2,1, -.000015
9,3,1, -.000015
THERMAL LOADS
1,
 14.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000011
8,2,1, -.000011
9,3,1, -.000011
THERMAL LOADS
1,
  7.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000108
8,2,1,  .000108
9,3,1,  .000108
THERMAL LOADS
1,
   .7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000063
8,2,1, -.000063
9,3,1, -.000063
THERMAL LOADS
1,
 -6.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000569
8,2,1,  .000569
9,3,1,  .000569
THERMAL LOADS
1,
-12.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .001229
8,2,1,  .001229
9,3,1,  .001229
THERMAL LOADS
1,
-19.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000086
8,2,1,  .000086
9,3,1,  .000086
THERMAL LOADS
1,
-25.6,1.250000

CONTINUE
BOUNDARY CHANGE
```

```
3,
7,1,1,  .000114
8,2,1,  .000114
9,3,1,  .000114
THERMAL LOADS
1,
-31.3,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000139
8,2,1,  .000139
9,3,1,  .000139
THERMAL LOADS
1,
-36.5,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000162
8,2,1,  .000162
9,3,1,  .000162
THERMAL LOADS
1,
-41.1,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000183
8,2,1,  .000183
9,3,1,  .000183
THERMAL LOADS
1,
-45.0,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000200
8,2,1,  .000200
9,3,1,  .000200
THERMAL LOADS
1,
-48.1,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000214
8,2,1,  .000214
9,3,1,  .000214
THERMAL LOADS
1,
-50.4,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000224
8,2,1,  .000224
9,3,1,  .000224
THERMAL LOADS
1,
-51.8,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000230
8,2,1,  .000230
9,3,1,  .000230
THERMAL LOADS
1,
-52.3,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000247
8,2,1,  .000247
9,3,1,  .000247
THERMAL LOADS
1,
-52.0,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000048
8,2,1,  .000048
9,3,1,  .000048
THERMAL LOADS
1,
-50.7,1.250000
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000047
8,2,1,  .000047
9,3,1,  .000047
THERMAL LOADS
1,
-48.6,1.250000
```

```
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000045
8,2,1,  .000045
9,3,1,  .000045
THERMAL LOADS
1,
-45.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000043
8,2,1,  .000043
9,3,1,  .000043
THERMAL LOADS
1,
-41.9,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000039
8,2,1,  .000039
9,3,1,  .000039
THERMAL LOADS
1,
-37.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000035
8,2,1,  .000035
9,3,1,  .000035
THERMAL LOADS
1,
-32.4,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000030
8,2,1,  .000030
9,3,1,  .000030
THERMAL LOADS
1,
-26.8,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000025
8,2,1,  .000025
9,3,1,  .000025
THERMAL LOADS
1,
-20.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000019
8,2,1,  .000019
9,3,1,  .000019
THERMAL LOADS
1,
-14.2,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000013
8,2,1,  .000013
9,3,1,  .000013
THERMAL LOADS
1,
 -7.5,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000106
8,2,1, -.000106
9,3,1, -.000106
THERMAL LOADS
1,
  -.7,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000063
8,2,1,  .000063
9,3,1,  .000063
THERMAL LOADS
1,
  6.1,1.250000

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000569
8,2,1, -.000569
9,3,1, -.000569
THERMAL LOADS
1,
 12.9,1.250000

CONTINUE
```

APPENDIX 8. DATA INPUT FOR OPEN NONSYMMETRIC TMF LOOP

```
TITLE      THERMOMECHANICAL LOOP NO. 3 WITH FUNCTIONAL THEORY
SIZING         15000     4    9    9    2   10
POST          2
ALL POINTS
INPUT TAPE    1
HYPOELAS
STATE VARS   16
NO LOADCOR    1
RESTART
END
MESH2D
BLOCKS
    1    4    10    1    1    9         6
DEFINE
    1    2    2    1    2    3    4
BOUNDARY
    1         1.
    2         1.         1.
    3         0.         1.
    4
CONSTRAINT
    2
    1    3    1
    1    4    2
MERGE
.0005
GENERATE
CONNECTIVITY
         1
COORDINATES
              1
BOUNDARY CONDITIONS
    0    1    1
BOUNDARY CONDITIONS
1,
1,3,1,1,1.E-8
THERMAL LOADS
1,
0.,1.E-8
PROPERTY
    1
    26.0E6       .322             0.E-5
    1    4
POST
    2   16   16
    1
   11
PRINT CHOICE
              1
```

```
     1
CONTROL
49,15,1,0
          .05
RESTART
1,1,0,8,8
INITIAL STATE
1,1,1
1,4,1,4
940.
END OPTION
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000085
8,2,1, -.000085
9,3,1, -.000085
THERMAL LOADS
1,
 19.5,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000166
8,2,1, -.000166
9,3,1, -.000166
THERMAL LOADS
1,
 38.1,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000274
8,2,1, -.000274
9,3,1, -.000274
THERMAL LOADS
1,
 54.8,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000344
8,2,1, -.000344
9,3,1, -.000344
THERMAL LOADS
1,
 68.9,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000378
8,2,1, -.000378
9,3,1, -.000378
THERMAL LOADS
1,
 79.6,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000411
8,2,1, -.000411
9,3,1, -.000411
THERMAL LOADS
1,
 86.5,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000424
8,2,1, -.000424
9,3,1, -.000424
THERMAL LOADS
1,
 89.2,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000401
8,2,1, -.000401
9,3,1, -.000401
THERMAL LOADS
1,
 87.6,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000374
8,2,1, -.000374
9,3,1, -.000374
THERMAL LOADS
```

```
1,
 81.8,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000246
8,2,1, -.000246
9,3,1, -.000246
THERMAL LOADS
1,
 72.0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000201
8,2,1, -.000201
9,3,1, -.000201
THERMAL LOADS
1,
 58.7,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000100
8,2,1, -.000100
9,3,1, -.000100
THERMAL LOADS
1,
 42.6,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000146
8,2,1,  .000146
9,3,1,  .000146
THERMAL LOADS
1,
 24.4,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000030
8,2,1,  .000030
9,3,1,  .000030
THERMAL LOADS
1,
  5.1,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
```

```
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166
```

```
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000027
8,2,1,  .000027
9,3,1,  .000027
THERMAL LOADS
1,
 -5.1,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000131
8,2,1,  .000131
9,3,1,  .000131
THERMAL LOADS
1,
-24.4,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000248
8,2,1,  .000248
9,3,1,  .000248
THERMAL LOADS
1,
-42.6,2.104166
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000342
8,2,1,  .000342
9,3,1,  .000342
THERMAL LOADS
1,
-58.7,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000420
8,2,1,  .000420
9,3,1,  .000420
THERMAL LOADS
1,
-72.0,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000462
8,2,1,  .000462
9,3,1,  .000462
THERMAL LOADS
1,
-81.8,2.104166
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000366
8,2,1,  .000366
9,3,1,  .000366
THERMAL LOADS
1,
-87.6,2.104167
CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000373
8,2,1,  .000373
```

```
9,3,1,  .000373
THERMAL LOADS
1,
-89.2,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000362
8,2,1,  .000362
9,3,1,  .000362
THERMAL LOADS
1,
-86.5,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000260
8,2,1,  .000260
9,3,1,  .000260
THERMAL LOADS
1,
-79.6,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000225
8,2,1,  .000225
9,3,1,  .000225
THERMAL LOADS
1,
-68.9,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000070
8,2,1,  .000070
9,3,1,  .000070
THERMAL LOADS
1,
-54.8,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000048
8,2,1,  .000048
9,3,1,  .000048
THERMAL LOADS
1,
-38.1,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000107
8,2,1, -.000107
9,3,1, -.000107
THERMAL LOADS
1,
-19.5,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000085
8,2,1, -.000085
9,3,1, -.000085
THERMAL LOADS
1,
 19.5,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000166
8,2,1, -.000166
9,3,1, -.000166
THERMAL LOADS
1,
 38.1,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000274
8,2,1, -.000274
9,3,1, -.000274
THERMAL LOADS
1,
 54.8,2.104166

CONTINUE
```

```
BOUNDARY CHANGE
3,
7,1,1, -.000344
8,2,1, -.000344
9,3,1, -.000344
THERMAL LOADS
1,
 68.9,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000378
8,2,1, -.000378
9,3,1, -.000378
THERMAL LOADS
1,
 79.6,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000411
8,2,1, -.000411
9,3,1, -.000411
THERMAL LOADS
1,
 86.5,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000424
8,2,1, -.000424
9,3,1, -.000424
THERMAL LOADS
1,
 89.2,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000401
8,2,1, -.000401
9,3,1, -.000401
THERMAL LOADS
1,
 87.6,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000374
8,2,1, -.000374
9,3,1, -.000374
THERMAL LOADS
1,
 81.8,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000246
8,2,1, -.000246
9,3,1, -.000246
THERMAL LOADS
1,
 72.0,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000201
8,2,1, -.000201
9,3,1, -.000201
THERMAL LOADS
1,
 58.7,2.104167

CONTINUE
BOUNDARY CHANGE
3,
7,1,1, -.000100
8,2,1, -.000100
9,3,1, -.000100
THERMAL LOADS
1,
 42.6,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000146
8,2,1,  .000146
9,3,1,  .000146
THERMAL LOADS
1,
 24.4,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000030
8,2,1,  .000030
9,3,1,  .000030
THERMAL LOADS
```

```
1,
   5.1,2.104168

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104168

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104168

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104168

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
```

```
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104168

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104168

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104168

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000000
8,2,1,  .000000
9,3,1,  .000000
THERMAL LOADS
1,
   .0,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000027
8,2,1,  .000027
9,3,1,  .000027
THERMAL LOADS
1,
 -5.1,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,  .000131
8,2,1,  .000131
9,3,1,  .000131
THERMAL LOADS
1,
-24.4,2.104168
```

```

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000248
8,2,1,   .000248
9,3,1,   .000248
THERMAL LOADS
1,
-42.6,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000342
8,2,1,   .000342
9,3,1,   .000342
THERMAL LOADS
1,
-58.7,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000420
8,2,1,   .000420
9,3,1,   .000420
THERMAL LOADS
1,
-72.0,2.104168

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000462
8,2,1,   .000462
9,3,1,   .000462
THERMAL LOADS
1,
-81.8,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000366
8,2,1,   .000366
9,3,1,   .000366
THERMAL LOADS
1,
-87.6,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000373
8,2,1,   .000373
9,3,1,   .000373
THERMAL LOADS
1,
-89.2,2.104168

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000362
8,2,1,   .000362
9,3,1,   .000362
THERMAL LOADS
1,
-86.5,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000260
8,2,1,   .000260
9,3,1,   .000260
THERMAL LOADS
1,
-79.6,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000225
8,2,1,   .000225
9,3,1,   .000225
THERMAL LOADS
1,
-68.9,2.104168

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000070
8,2,1,   .000070
9,3,1,   .000070
THERMAL LOADS
1,
-54.8,2.104166

CONTINUE
BOUNDARY CHANGE
3,
7,1,1,   .000048
8,2,1,   .000048
9,3,1,   .000048
THERMAL LOADS
1,
-38.1,2.104166

CONTINUE
```