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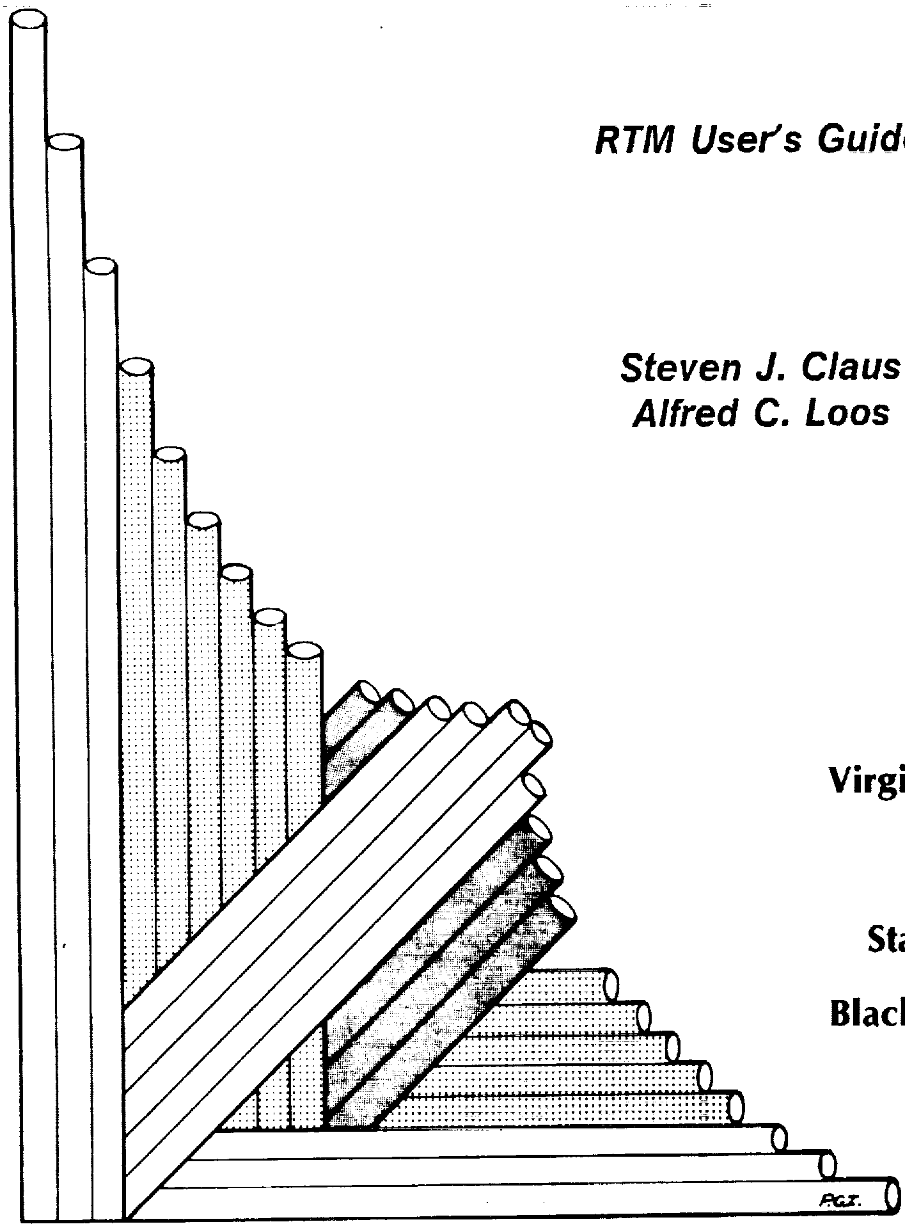

RTM User's Guide

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Institute
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RTM User's Guide

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ABSTRACT

RTM is a Fortran '77 computer code which simulates the infiltration of textile reinforcements and the kinetics of thermosetting polymer resin systems. The computer code is based on the process simulation model developed by the author [1]. The compaction of dry, woven textile composites is simulated to describe the increase in fiber volume fraction with increasing compaction pressure. Infiltration is assumed to follow D'Arcy's law for Newtonian viscous fluids. The chemical changes which occur in the resin during processing are simulated with a thermo-kinetics model. The computer code is discussed on the basis of the required input data, output files and some comments on how to interpret the results. An example problem is solved and a complete listing is included.

Acknowledgements

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1.0 Table of Contents

2.0 List of Illustrations

3.0 RTM

An infiltration/cure model was developed to simulate the production of composite laminates from advanced textile fabrics and thermosetting resin systems by the resin transfer molding process [1]. The model is composed of two sections: an infiltration model and a cure model.

The infiltration model simulates the flow of a reactive resin system into a dry textile preform. The resin viscosity and degree of cure are calculated from a kinetics model assuming the resin temperature to be the same as the applied temperature. Position of the infiltration front, resin viscosity, degree of cure, and velocity are calculated as a function of time assuming the textile preform to behave as an elastic porous medium which is infiltrated with a Newtonian viscous fluid. Results from the infiltration model include,

1. Material thickness
2. Permeability
3. Porosity
4. Total resin mass
5. Position of the infiltration front
6. Resin degree of cure
7. Resin viscosity
8. Resin velocity.

The cure model is initiated when the material is completely infiltrated and is used to predict the changes in the resin system as the cure cycle progresses. During this stage of the simulation the resin is assumed to be stationary. Heat transfer into the composite laminate is simulated with a transient heat transfer sub-model which includes generation of heat by exothermic chemical reactions. Results of the cure model include; temperature, resin degree of cure, and resin viscosity as functions of position and time.

Due to the nonlinear formulation of the governing equations, the solution of the infiltration and cure models was accomplished by numerical techniques. The infiltration model is solved by a finite element technique and the cure model is solved by a finite difference technique. A Fortran '77 computer code was written to solve the models and a listing of the computer code is given in Appendix A.

3.1 Infiltration Model

Solution of the infiltration model was accomplished with an eight-node quadrilateral finite element technique. Infiltration was assumed to occur in one direction only. Motion of the resin was simulated by adding an element to the computational mesh at each time step of length,

$$\Delta z = v_z \Delta t$$

where Δz represents the length of the new element, v sub z represents the velocity at the infiltration front, and Δt represents the time step. A logic diagram for the infiltration solution is shown in Figure 1.

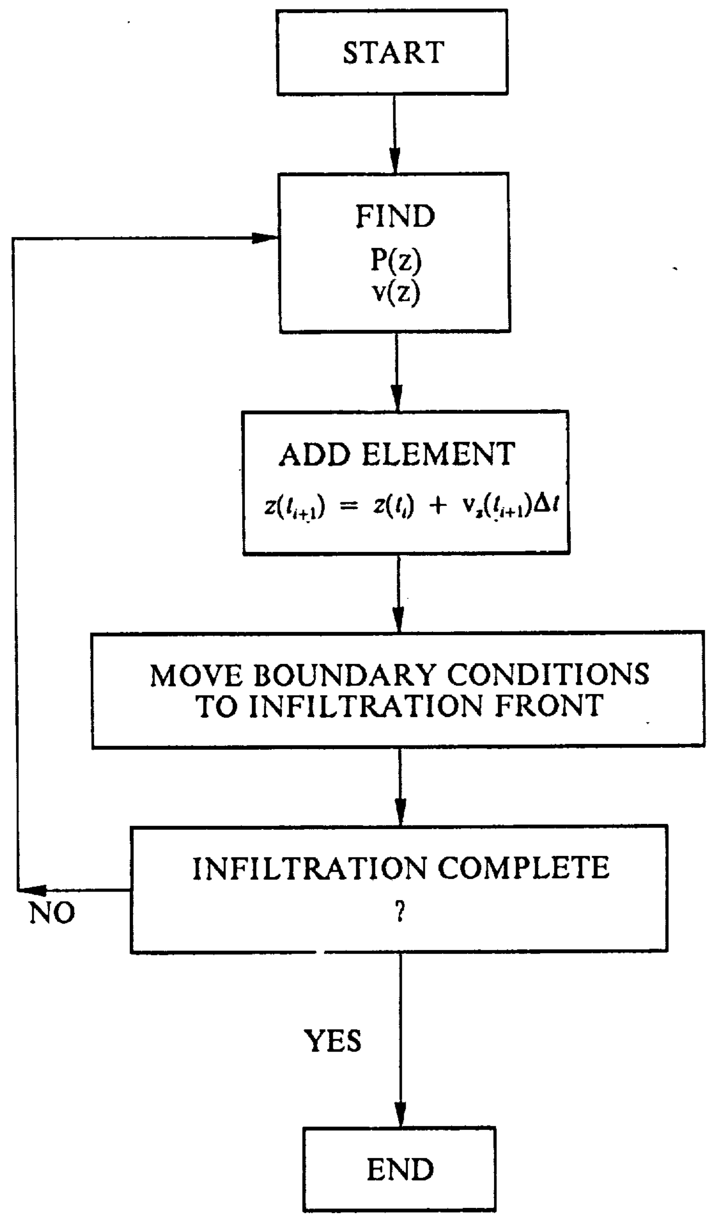

Figure 1. Logic diagram for the quasi-steady state infiltration process.

In this numerical scheme, the time increment is calculated according to the following expressions,

$$\Delta t(t_{i+1}) = RPos(t_{i+1}) + \Delta t(t_i)$$

for $Pos(t_{i+1}) < PosA$,

$$\Delta t(t_{i+1}) = Btime$$

for $PosA < Pos(t_{i+1}) < PosB$, and

$$\Delta t(t_{i+1}) = Ctime$$

for $PosB < Pos(t_{i+1}) < PosC$ where R represents the rate of change of the time increment, Pos represents the position of the infiltration front in percent, $PosA$, $PosB$ represent two distinct hold positions, and $Btime$, $Ctime$ represent two constant time steps.

The required input for the infiltration model includes the temperature history and pressures applied to the resin and fabric.

3.2 Cure Model

Solution of the cure model was accomplished by a finite difference technique. Using the known properties of the composite and tooling materials and the applied cure temperature, the system of transient heat equations was solved to obtain the temperature within the composite as a function of time. The degree of cure and viscosity of the resin are calculated with the known temperature distribution. Figure 2 is a flow chart for the computations necessary for the solution of the infiltration and cure models.

The necessary input parameters for RTM are as follows:

Problem Geometry:

1. Length of the composite
2. Width of the composite

Solid Material Characteristics:

1. Number of layers
2. Areal weight
3. Uncompacted thickness
4. Fiber diameter
5. Fiber density
6. Compaction coefficients
7. Kozeny-Carman coefficients

Time Step Coefficients:

1. Thickness Fraction for the First Time Increment
2. Thickness Fraction for the Second Time Increment
3. Rate Coefficient of the Time Scheme
4. First Hold Time Step
5. Second Hold Time Step

Applied Pressures:

1. Autoclave Pressure
2. Vacuum Bag Pressure

Heat Transfer Characteristics:

1. Number of divisions in the tool plate
2. Number of divisions in the composite
3. Number of divisions in the breather plies
4. Initial temperature
5. Total heat of reaction of the resin
6. Thermal conductivities of each material
7. Convective heat transfer coefficients of the boundary materials
8. Temperature history of the environment

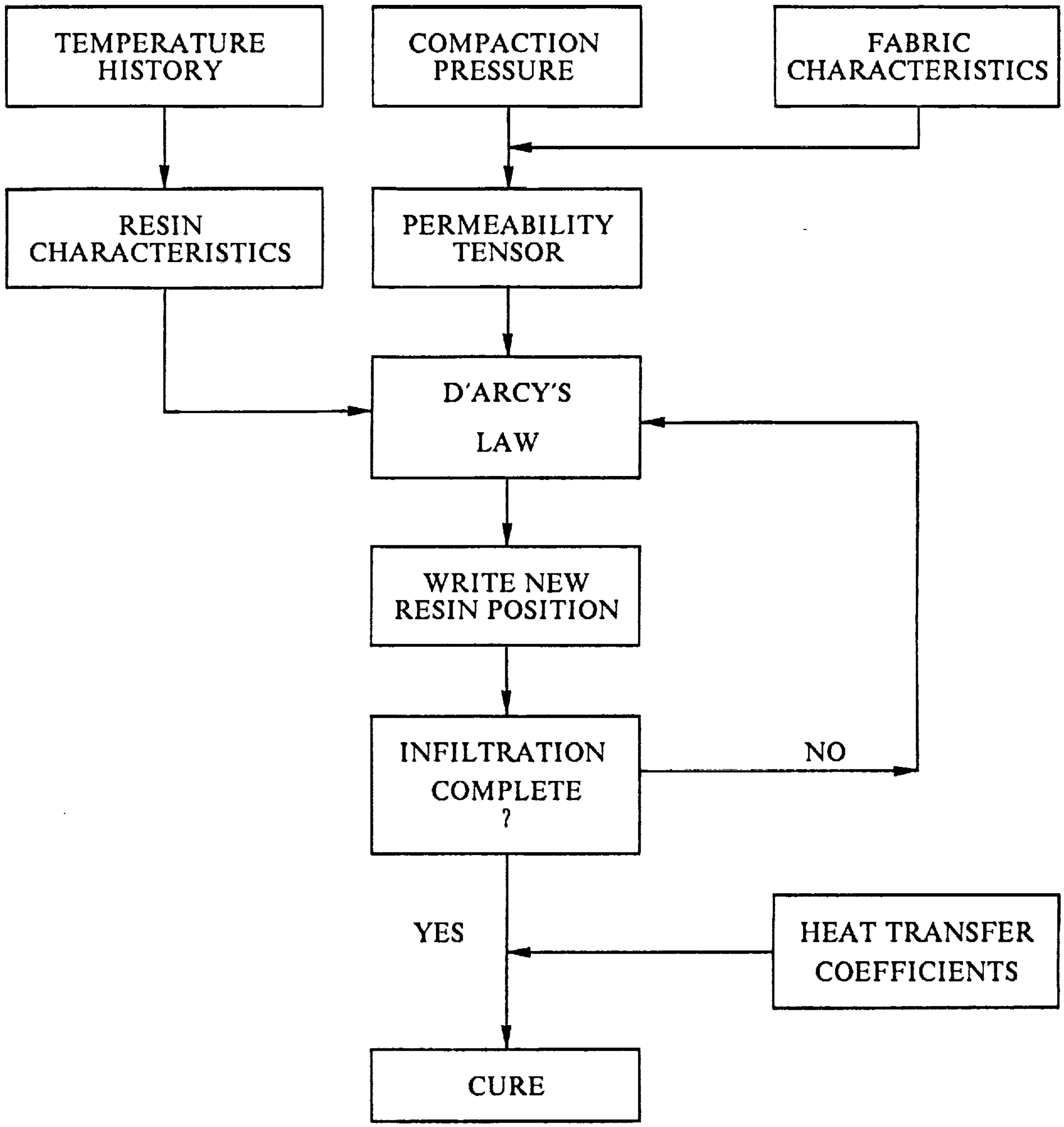

Figure 2. Computational flow chart for infiltration and cure models.

4.0 COMPUTER PROGRAM INSTRUCTIONS

This chapter contains a line-by-line description of the input data required to run the computer program RTM, and some comments on how the output is formulated and can be interpreted.

4.1 Interactive Input

During execution of RTM, the names of four files must be specified. The first file contains the input data for the simulation and the content of this file is explained in detail in the next section. The last three files are output files which contain the complete listing, plotting data for the infiltration phase, and plotting data for the cure phase, respectively. An interactive prompt is given for each file name.

4.2 Input Data Description

With the exception of input data Card 1, all input is format free.

Value	Description
Card 1 (18A4)	
ANAME	Title of the problem
Card 2	
NTIMES	Number of time steps
NTEMPS	Number of temperature steps in infiltration and cure cycles
IVSWH	Viscosity switch = 1 Temperature dependant viscosity = 0 Constant viscosity
IRESIN	Resin switch = 1 Hercules 3501-6 = 2 Shell RSL1282/9470 32.4 PHR
ICURE	Curing switch = 0 Cure cycle is not simulated = 1 Cure cycle is simulated
Card 3	
RLGTH	Length of laminate
WIDTH	Width of laminate
Card 4 thru Card 4+NTEMPS	
TIMEIN	Time of temperature change
TAUTO	Temperature in autoclave at TIMEIN
	NOTE: If IVSWH = 0 then substitute the cards above w the fluid viscosity

Card 4+NTEMPS+1

NPLIES	Number of plies of material
ZETA	Areal weight of fabric
DIAFI	Diameter of individual filaments
RHOFI	Density of solid material
TUNCPT	Thickness of uncompacted ply
RKCC	Kozeny-Carman constant
PZERO	Pressure at which d = 0 (PZERO>0)

Card 4+NTEMPS+2

A(J)	Coefficients of the compaction model

Card 4+NTEMPS+3

POSA	Thickness fraction for first time increment hold
POSB	Thickness fraction for second time increment hold
ATIME	Rate coefficient of the time scheme
BTIME	First hold time step
CTIME	Second hold time step

Card 4+NTEMPS+4

PAUTO	Pressure in the autoclave or applied by platens
PBAG	Pressure in the bleeder or dry material

NOTE: all pressures in gage

Card 4+NTEMPS+5

NTOOL	Number of divisions in tool plate
NPRESS	Number of divisions in pressure plate
IFREQ	Frequency of printout....with respect to time
IRED	Frequency of printout....with respect to position

Card 4+NTEMPS+6

CPFL	Specific heat of the resin
CPFI	Specific heat of the fiber
KTFL	Thermal conductivity of the resin
KTFI	Thermal conductivity of the fiber

HR	Heat of reaction of the resin

Card 4+NTEMPS+7

DELZ	Time step for calculation during cure
VEL	Heat transfer coefficient

Card 4+NTEMPS+8

ZTOOL	Thickness of the tool plate
KTOOL	Thermal conductivity of the tool plate
RHOTOL	Density of the tool plate
CPTOOL	Specific heat of the tool plate

Card 4+NTEMPS+9

ZPRES	Thickness of the pressure plate
KPRES	Thermal conductivity of the pressure plate
RHOPRE	Density of the pressure plate
CPPRES	Specific heat of the pressure plate
NBLEED	Number of bleeder plies

NOTE: All units should be in SI except the compaction coefficients.

Two items which relate to the numerical solution should be discussed at this time. First, if the number of time steps and the time increment history are not sufficient to complete the simulation of the infiltration, the cure simulation will not be performed regardless of the value of ICURE. Second, when the infiltration simulation is completed the numerical solution should be checked by plotting the position of the infiltration front versus time. This curve should be smooth during the entire simulation.

5.0 EXAMPLE

The simulation of the production of a laminate with 16 plies of IM7/8HS fabric infiltrated and cured with Shell 1282/9470 is shown in the next several sections. Temperature cycle for infiltration and cure consisted of heating the laminate from 20°C to 80°C and holding for 1 hour. Additional holds at 120, 145, and 177°C were also used to completely cure the resin. A pressure of 70 kPa was applied to the dry material for infiltration and consolidation.

5.1 Input Data File

```
0 PSI CURE W/ SHELL RESIN
70 10 1 2 1
0.17145D0 0.1524D0
   0.0E+0  20.0E+0
 1200.0E+0  80.0E+0
 4800.0E+0  80.0E+0
```

```
 5600.0E+0 120.0E+0
 9200.0E+0 120.0E+0
 9700.0E+0 145.0E+0
13300.0E+0 145.0E+0
13940.0E+0 177.0E+0
17540.0E+0 177.0E+0
19480.0E+0  80.0E+0
16 0.44012896D0 4.9784D-6 1.7798D3 6.096D-4 2.8798D0 1.697894D3
6.313D-3  -4.935D-3  1.009D-3  -4.866D-5 0.0D0
0.15D0 0.3D0 0.5E0 0.7D0 2.0D0
68.95E+3 0.0D0
8 4 20 4
2.0934E3 7.1176E2 0.207696E0 0.259770E2 0.288E6
5.0E0 0.1E5
6.35E-3 0.20250E3 0.27074E4 0.87090E3
3.175E-3 0.20250E3 0.27074E4 0.87090E3 0
```

5.2 Program Listing

```
0 PSI CURE W/ SHELL RESIN


INPUT:
PROBLEM PARAMETERS:
    NUMBER OF TIME STEPS . . . . . . . . . . . . . . . .  70
```

NUMBER OF TEMPERATURE CHANGES. 10
VISCOSITY SWITCH (1 = TEMP DEPEND, 0 = CONSTANT) . 1
RESIN TYPE 2
CURE SWITCH (0 = NO CURE, 1 = CURE). 1

MATERIAL CHARACTERISTICS:

LAMINATE LENGTH. 1.7145000E-01
LAMINATE WIDTH 1.5240000E-01

CHARACTERISTICS OF THE TEMPERATURE PROFILE:

TIME OF TEMP CHANGE	AUTOCLAVE TEMP
.0000000E+00	2.0000000E+01
1.2000000E+03	8.0000000E+01
4.8000000E+03	8.0000000E+01
5.6000000E+03	1.2000000E+02
9.2000000E+03	1.2000000E+02
9.7000000E+03	1.4500000E+02
1.3300000E+04	1.4500000E+02
1.3940000E+04	1.7700000E+02
1.7540000E+04	1.7700000E+02
1.9480000E+04	8.0000000E+01

PRESSURES:
AUTOCLAVE PRESSURE . . . 6.8950000E+04
BAG PRESSURE . . . . . . .0000000E+00
COMPACTION PRESSURE. . . 6.8950000E+04

SOLID PROPERTIES:

NUMBER OF PLIES. 16
AREAL WEIGHT 4.4012896E-01
DIAMETER OF FIBER. . . . 4.9784000E-06
DENSITY OF FIBER . . . . 1.7798000E+03
UNCOMPACTED THICKNESS. . 6.0960000E-04
KOZENY-CARMEN CONSTANT . 2.8798000E+00
PRESSURE AT ZERO DEFL. . 1.6978940E+03

MATERIAL COEFFICIENTS. .

6.3130000E-03 -4.9350000E-03 1.0090000E-03 -4.8660000E-05
0.0000000E+00

TIME INCRIMENTS:
TIME COEFF A 5.0000000E-01
FIRST HOLD POSITION. . . 1.5000000E-01
TIME COEFF B 7.0000000E-01
SECOND HOLD POSITION . . 3.0000000E-01
TIME COEFF C . . . . . . 2.0000000E+00

MATERIAL RESULTS:
LAMINATE THICKNESS . . . 8.6092915E-03
POROSITY 5.4041980E-01
TOTAL RESIN VOLUME . . . 1.2156852E-04
PERMEABILITY 6.4311461E-12

RESIN MASS 1.4077634E-01

TIME	TEMP	POSIT. OF INFILTRATION	DEGREE OF CURE	FLUID VISCOSITY	VELOCITY
.0000E+00	2.0000E+01	.0000E+00	8.6387E-22	7.2338E-01	1.1071E+07
1.0000E-15	2.0000E+01	1.2860E-06	1.2958E-21	7.2338E-01	5.5367E+01
6.4299E-07	2.0000E+01	4.1364E-03	2.7773E-13	7.2338E-01	1.7213E-02
2.0689E-03	2.0000E+01	8.2716E-03	8.9362E-10	7.2337E-01	8.6080E-03
6.2047E-03	2.0000E+01	1.2407E-02	2.6805E-09	7.2336E-01	5.7390E-03
1.2408E-02	2.0001E+01	1.6542E-02	5.3613E-09	7.2335E-01	4.3045E-03
2.0679E-02	2.0001E+01	2.0677E-02	8.9365E-09	7.2333E-01	3.4437E-03
3.1018E-02	2.0002E+01	2.4813E-02	1.3407E-08	7.2331E-01	2.8698E-03
4.3424E-02	2.0002E+01	2.8948E-02	1.8772E-08	7.2328E-01	2.4599E-03
5.7898E-02	2.0003E+01	3.3084E-02	2.5034E-08	7.2325E-01	2.1525E-03
7.4440E-02	2.0004E+01	3.7220E-02	3.2193E-08	7.2321E-01	1.9134E-03
9.3050E-02	2.0005E+01	4.1356E-02	4.0249E-08	7.2317E-01	1.7222E-03
1.1373E-01	2.0006E+01	4.5493E-02	4.9203E-08	7.2312E-01	1.5657E-03
1.3647E-01	2.0007E+01	4.9629E-02	5.9056E-08	7.2307E-01	1.4353E-03
1.6129E-01	2.0008E+01	5.3766E-02	6.9808E-08	7.2301E-01	1.3250E-03
1.8817E-01	2.0009E+01	5.7903E-02	8.1461E-08	7.2295E-01	1.2304E-03
2.1712E-01	2.0011E+01	6.2041E-02	9.4015E-08	7.2289E-01	1.1484E-03
2.4814E-01	2.0012E+01	6.6179E-02	1.0747E-07	7.2281E-01	1.0767E-03
2.8123E-01	2.0014E+01	7.0317E-02	1.2183E-07	7.2274E-01	1.0135E-03

3.1639E-01	2.0016E+01	7.4456E-02	1.3709E-07	7.2266E-01	9.5724E-04
3.5362E-01	2.0018E+01	7.8595E-02	1.5326E-07	7.2258E-01	9.0693E-04
3.9292E-01	2.0020E+01	8.2735E-02	1.7033E-07	7.2249E-01	8.6166E-04
4.3429E-01	2.0022E+01	8.6875E-02	1.8831E-07	7.2239E-01	8.2070E-04
4.7772E-01	2.0024E+01	9.1016E-02	2.0720E-07	7.2230E-01	7.8347E-04
5.2323E-01	2.0026E+01	9.5158E-02	2.2699E-07	7.2219E-01	7.4948E-04
5.7081E-01	2.0029E+01	9.9300E-02	2.4770E-07	7.2208E-01	7.1832E-04
6.2046E-01	2.0031E+01	1.0344E-01	2.6931E-07	7.2197E-01	6.8966E-04
6.7218E-01	2.0034E+01	1.0759E-01	2.9184E-07	7.2186E-01	6.6321E-04
7.2597E-01	2.0036E+01	1.1173E-01	3.1528E-07	7.2173E-01	6.3872E-04
7.8184E-01	2.0039E+01	1.1587E-01	3.3963E-07	7.2161E-01	6.1598E-04
8.3978E-01	2.0042E+01	1.2002E-01	3.6490E-07	7.2148E-01	5.9482E-04
8.9979E-01	2.0045E+01	1.2417E-01	3.9109E-07	7.2134E-01	5.7506E-04
9.6187E-01	2.0048E+01	1.2831E-01	4.1819E-07	7.2120E-01	5.5659E-04
1.0260E+00	2.0051E+01	1.3246E-01	4.4621E-07	7.2106E-01	5.3927E-04
1.0923E+00	2.0055E+01	1.3661E-01	4.7515E-07	7.2091E-01	5.2300E-04
1.1606E+00	2.0058E+01	1.4076E-01	5.0501E-07	7.2075E-01	5.0769E-04
1.2309E+00	2.0062E+01	1.4491E-01	5.3580E-07	7.2059E-01	4.9326E-04
1.3034E+00	2.0065E+01	1.4906E-01	5.6750E-07	7.2043E-01	4.7963E-04
1.3779E+00	2.0069E+01	1.5321E-01	6.0014E-07	7.2026E-01	4.6674E-04
2.0779E+00	2.0104E+01	1.9116E-01	9.0727E-07	7.1868E-01	3.7490E-04
2.7779E+00	2.0139E+01	2.2164E-01	1.2158E-06	7.1711E-01	3.2405E-04
3.4779E+00	2.0174E+01	2.4799E-01	1.5256E-06	7.1554E-01	2.9026E-04
4.1779E+00	2.0209E+01	2.7159E-01	1.8367E-06	7.1397E-01	2.6562E-04
4.8779E+00	2.0244E+01	2.9319E-01	2.1489E-06	7.1241E-01	2.4659E-04
5.5779E+00	2.0279E+01	3.1324E-01	2.4622E-06	7.1085E-01	2.3131E-04
7.5779E+00	2.0379E+01	3.6697E-01	3.3635E-06	7.0642E-01	1.9868E-04
9.5779E+00	2.0479E+01	4.1313E-01	4.2733E-06	7.0202E-01	1.7759E-04
1.1578E+01	2.0579E+01	4.5438E-01	5.1914E-06	6.9765E-01	1.6248E-04
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1.5578E+01	2.0779E+01	5.2720E-01	7.0515E-06	6.8900E-01	1.4180E-04
1.7578E+01	2.0879E+01	5.6014E-01	7.9931E-06	6.8472E-01	1.3429E-04
1.9578E+01	2.0979E+01	5.9133E-01	8.9423E-06	6.8047E-01	1.2800E-04
2.1578E+01	2.1079E+01	6.2107E-01	9.8990E-06	6.7625E-01	1.2263E-04
2.3578E+01	2.1179E+01	6.4956E-01	1.0863E-05	6.7205E-01	1.1799E-04
2.5578E+01	2.1279E+01	6.7697E-01	1.1835E-05	6.6789E-01	1.1392E-04
2.7578E+01	2.1379E+01	7.0343E-01	1.2814E-05	6.6376E-01	1.1031E-04
2.9578E+01	2.1479E+01	7.2906E-01	1.3800E-05	6.5965E-01	1.0710E-04
3.1578E+01	2.1579E+01	7.5394E-01	1.4793E-05	6.5557E-01	1.0421E-04
3.3578E+01	2.1679E+01	7.7814E-01	1.5794E-05	6.5152E-01	1.0159E-04
3.5578E+01	2.1779E+01	8.0175E-01	1.6802E-05	6.4750E-01	9.9216E-05
3.7578E+01	2.1879E+01	8.2479E-01	1.7818E-05	6.4350E-01	9.7042E-05
3.9578E+01	2.1979E+01	8.4734E-01	1.8841E-05	6.3953E-01	9.5046E-05
4.1578E+01	2.2079E+01	8.6942E-01	1.9871E-05	6.3559E-01	9.3207E-05
4.3578E+01	2.2179E+01	8.9107E-01	2.0908E-05	6.3168E-01	9.1506E-05
4.5578E+01	2.2279E+01	9.1233E-01	2.1952E-05	6.2779E-01	8.9927E-05
4.7578E+01	2.2379E+01	9.3322E-01	2.3004E-05	6.2393E-01	8.8458E-05
4.9578E+01	2.2479E+01	9.5377E-01	2.4063E-05	6.2010E-01	8.7087E-05
5.1578E+01	2.2579E+01	9.7400E-01	2.5130E-05	6.1629E-01	8.5805E-05
5.3578E+01	2.2679E+01	9.9393E-01	2.6204E-05	6.1251E-01	8.4604E-05
5.4195E+01	2.2710E+01	1.0000E+00	2.7281E-05	6.1134E-01	8.4604E-05

**** INFILTRATION COMPLETE ****

RESIN PROPERTIES
CP = .20934E+04
KT = .20770E+00
HR = .28800E+06

FIBER PROPERTIES
CP = .71176E+03
KT = .25977E+02

PLY PROPERTIES
RHO = .14438E+04
CP = .13106E+04
KTZ = .50187E+00

TOOL PLATE PROPERTIES
THICK = .63500E-02
RHO = .27074E+04
CP = .87090E+03
KT = .20250E+03

PRESSURE PLATE PROPERTIES
THICK = .31750E-02
RHO = .27074E+04
CP = .87090E+03
KT = .20250E+03

PROGRAM CONSTANTS
DELT = .50000E+01
VEL = .10000E+05

OPTIONS
IFREQ = 200
IRED = 4

TIME = .105420E+04 TAIR = 72.7

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.725708E+02	.294477E-02	.446580E-01	.00000
13	.215232E-02	.712912E+02	.277224E-02	.472844E-01	.25000
17	.430465E-02	.708731E+02	.271813E-02	.481807E-01	.50000
21	.645697E-02	.713171E+02	.277564E-02	.472295E-01	.75000
25	.860929E-02	.726226E+02	.295199E-02	.445553E-01	1.00000

TTOOL = .725950E+02 TPLATE = .726319E+02

TIME = .205420E+04 TAIR = 80.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.800020E+02	.177532E-01	.339916E-01	.00000
13	.215232E-02	.800499E+02	.173122E-01	.338686E-01	.25000
17	.430465E-02	.800658E+02	.171715E-01	.338286E-01	.50000
21	.645697E-02	.800498E+02	.173210E-01	.338698E-01	.75000
25	.860929E-02	.800017E+02	.177715E-01	.339942E-01	1.00000

TTOOL = .800015E+02 TPLATE = .800015E+02

TIME = .305420E+04 TAIR = 80.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.800029E+02	.421976E-01	.371496E-01	.00000
13	.215232E-02	.800746E+02	.415959E-01	.369603E-01	.25000
17	.430465E-02	.800984E+02	.414040E-01	.368987E-01	.50000
21	.645697E-02	.800745E+02	.416089E-01	.369623E-01	.75000
25	.860929E-02	.800026E+02	.422244E-01	.371538E-01	1.00000

TTOOL = .800022E+02 TPLATE = .800022E+02

TIME = .405420E+04 TAIR = 80.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.800039E+02	.762376E-01	.420455E-01	.00000
13	.215232E-02	.801000E+02	.755332E-01	.417820E-01	.25000
17	.430465E-02	.801318E+02	.753094E-01	.416964E-01	.50000

21	.645697E-02	.800997E+02	.755503E-01	.417850E-01	.75000
25	.860929E-02	.800035E+02	.762728E-01	.420517E-01	1.00000

TTOOL = .800030E+02 TPLATE = .800030E+02

TIME = .505420E+04 TAIR = 92.7

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.925767E+02	.122645E+00	.324305E-01	.00000
13	.215232E-02	.914406E+02	.121430E+00	.334673E-01	.25000
17	.430465E-02	.910695E+02	.121049E+00	.338194E-01	.50000
21	.645697E-02	.914662E+02	.121462E+00	.334440E-01	.75000
25	.860929E-02	.926278E+02	.122711E+00	.323867E-01	1.00000

TTOOL = .925995E+02 TPLATE = .926364E+02

TIME = .605420E+04 TAIR = 120.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.120025E+03	.297339E+00	.462572E-01	.00000
13	.215232E-02	.120628E+03	.294262E+00	.450644E-01	.25000
17	.430465E-02	.120829E+03	.293288E+00	.446872E-01	.50000
21	.645697E-02	.120627E+03	.294390E+00	.451028E-01	.75000
25	.860929E-02	.120022E+03	.297582E+00	.463316E-01	1.00000

TTOOL = .120019E+03 TPLATE = .120019E+03

TIME = .705420E+04 TAIR = 120.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.120022E+03	.531046E+00	.211496E+00	.00000
13	.215232E-02	.120571E+03	.530511E+00	.211914E+00	.25000
17	.430465E-02	.120755E+03	.530371E+00	.212112E+00	.50000
21	.645697E-02	.120570E+03	.530621E+00	.212063E+00	.75000
25	.860929E-02	.120020E+03	.531255E+00	.211779E+00	1.00000

TTOOL = .120017E+03 TPLATE = .120017E+03

TIME = .805420E+04 TAIR = 120.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.120016E+03	.718074E+00	.714691E+00	.00000
13	.215232E-02	.120408E+03	.718432E+00	.723659E+00	.25000
17	.430465E-02	.120539E+03	.718580E+00	.726832E+00	.50000
21	.645697E-02	.120407E+03	.718508E+00	.724002E+00	.75000
25	.860929E-02	.120014E+03	.718219E+00	.715335E+00	1.00000

TTOOL = .120012E+03 TPLATE = .120012E+03

TIME = .905420E+04 TAIR = 120.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.120010E+03	.841983E+00	.160195E+01	.00000
13	.215232E-02	.120251E+03	.842365E+00	.162010E+01	.25000
17	.430465E-02	.120332E+03	.842511E+00	.162643E+01	.50000
21	.645697E-02	.120251E+03	.842411E+00	.162056E+01	.75000
25	.860929E-02	.120009E+03	.842072E+00	.160281E+01	1.00000

TTOOL = .120008E+03 TPLATE = .120008E+03

TIME = .100542E+05 TAIR = 145.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.145010E+03	.951032E+00	.130465E+02	.00000
13	.215232E-02	.145258E+03	.950673E+00	.132169E+02	.25000
17	.430465E-02	.145342E+03	.950590E+00	.132796E+02	.50000
21	.645697E-02	.145257E+03	.950715E+00	.132213E+02	.75000
25	.860929E-02	.145009E+03	.951120E+00	.130556E+02	1.00000

TTOOL = .145008E+03 TPLATE = .145008E+03

TIME = .110542E+05 TAIR = 145.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.145002E+03	.992622E+00	.188824E+02	.00000
13	.215232E-02	.145039E+03	.992705E+00	.189452E+02	.25000
17	.430465E-02	.145051E+03	.992739E+00	.189673E+02	.50000
21	.645697E-02	.145038E+03	.992711E+00	.189461E+02	.75000
25	.860929E-02	.145001E+03	.992635E+00	.188843E+02	1.00000

TTOOL = .145001E+03 TPLATE = .145001E+03

TIME = .120542E+05 TAIR = 145.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.145000E+03	.998916E+00	.199692E+02	.00000
13	.215232E-02	.145006E+03	.998932E+00	.199796E+02	.25000
17	.430465E-02	.145007E+03	.998938E+00	.199832E+02	.50000
21	.645697E-02	.145006E+03	.998933E+00	.199797E+02	.75000
25	.860929E-02	.145000E+03	.998918E+00	.199695E+02	1.00000

TTOOL = .145000E+03 TPLATE = .145000E+03

TIME = .130542E+05 TAIR = 145.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.145000E+03	.999841E+00	.201341E+02	.00000
13	.215232E-02	.145001E+03	.999844E+00	.201357E+02	.25000
17	.430465E-02	.145001E+03	.999845E+00	.201362E+02	.50000
21	.645697E-02	.145001E+03	.999844E+00	.201357E+02	.75000
25	.860929E-02	.145000E+03	.999842E+00	.201342E+02	1.00000

TTOOL = .145000E+03 TPLATE = .145000E+03

TIME = .140542E+05 TAIR = 177.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.176999E+03	.999993E+00	.287100E+03	.00000
13	.215232E-02	.176962E+03	.999992E+00	.287377E+03	.25000
17	.430465E-02	.176947E+03	.999992E+00	.287491E+03	.50000
21	.645697E-02	.176962E+03	.999992E+00	.287376E+03	.75000
25	.860929E-02	.176999E+03	.999993E+00	.287098E+03	1.00000

TTOOL = .176999E+03 TPLATE = .176999E+03

TIME = .150542E+05 TAIR = 177.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.177000E+03	.100000E+01	.287116E+03	.00000
13	.215232E-02	.177000E+03	.100000E+01	.287116E+03	.25000

17	.430465E-02	.177000E+03	.100000E+01	.287116E+03	.50000
21	.645697E-02	.177000E+03	.100000E+01	.287116E+03	.75000
25	.860929E-02	.177000E+03	.100000E+01	.287116E+03	1.00000

TTOOL = .177000E+03 TPLATE = .177000E+03

TIME = .160542E+05 TAIR = 177.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.177000E+03	.100000E+01	.287116E+03	.00000
13	.215232E-02	.177000E+03	.100000E+01	.287116E+03	.25000
17	.430465E-02	.177000E+03	.100000E+01	.287116E+03	.50000
21	.645697E-02	.177000E+03	.100000E+01	.287116E+03	.75000
25	.860929E-02	.177000E+03	.100000E+01	.287116E+03	1.00000

TTOOL = .177000E+03 TPLATE = .177000E+03

TIME = .170542E+05 TAIR = 177.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.177000E+03	.100000E+01	.287116E+03	.00000
13	.215232E-02	.177000E+03	.100000E+01	.287116E+03	.25000
17	.430465E-02	.177000E+03	.100000E+01	.287116E+03	.50000
21	.645697E-02	.177000E+03	.100000E+01	.287116E+03	.75000
25	.860929E-02	.177000E+03	.100000E+01	.287116E+03	1.00000

TTOOL = .177000E+03 TPLATE = .177000E+03

TIME = .180542E+05 TAIR = 151.3

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.151430E+03	.100000E+01	.322806E+02	.00000
13	.215232E-02	.152727E+03	.100000E+01	.356419E+02	.25000
17	.430465E-02	.153151E+03	.100000E+01	.368251E+02	.50000
21	.645697E-02	.152701E+03	.100000E+01	.355709E+02	.75000
25	.860929E-02	.151378E+03	.100000E+01	.321539E+02	1.00000

TTOOL = .151406E+03 TPLATE = .151369E+03

TIME = .190542E+05 TAIR = 101.3

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.101430E+03	.100000E+01	.206639E+01	.00000
13	.215232E-02	.102727E+03	.100000E+01	.216064E+01	.25000
17	.430465E-02	.103151E+03	.100000E+01	.219304E+01	.50000
21	.645697E-02	.102701E+03	.100000E+01	.215869E+01	.75000
25	.860929E-02	.101378E+03	.100000E+01	.206277E+01	1.00000

TTOOL = .101406E+03 TPLATE = .101369E+03

TIME = .194842E+05 TAIR = 80.0

I	Z(I)	T(I)	CALPHA(I)	VISC(I)	Z/ZI
9	.000000E+00	.800784E+02	.100000E+01	.121939E+01	.00000
13	.215232E-02	.812509E+02	.100000E+01	.124257E+01	.25000
17	.430465E-02	.816585E+02	.100000E+01	.125108E+01	.50000
21	.645697E-02	.812287E+02	.100000E+01	.124211E+01	.75000
25	.860929E-02	.800508E+02	.100000E+01	.121887E+01	1.00000

TTOOL = .800632E+02 TPLATE = .800447E+02

6.0 REFERENCES

1. Claus, S.J., "A Cure Process Model for Resin Transfer Molding of Advanced Composites", M.S. Thesis, Department of Engineering Science and Mechanics, Virginia Polytechnic Institute and State University, April, 1989.

7.0 APPENDIX A

7.1 Main Program

```
C
C    INFILTRATION MODEL AND CURE MODELS FOR 1-D RESIN TRANSFER MOLDING
C
C  ASSUMPTIONS:
C    1. THREE STAGE RAMP-HOLD INFILTRATION TEMPERATURE PROFILE
C    2. HOMOGENOUS POROUS MEDIUM
C    3. CONSTANT COMPACTION PRESSURE
C    4. NEWTONIAN FLUID
C
C    CONTACT- STEVE CLAUS DEPT OF ESM VPI&SU. BLACKSBURG VA 24061
C
C
C  INPUT DATA FORMAT
C
C     LINE 1 : ANAME
C       ANAME  = TITLE OF THE PROBLEM
C
C     LINE 2 : NTIMES, NTEMPS, IVSWH, IRESIN, ICURE
C       NTIMES = NUMBER OF TIME STEPS FOR EACH PROBLEM
C       NTEMPS = NUMBER OF TEMPERATURE STEPS IN INFILTRATION AND CURE
C                CYCLES
C       IVSWH  = VISCOSITY SWITCH
C              = 1 TEMPERATURE DEPENDANT VISCOSITY
C              = 0 CONSTANT VISCOSITY
C       IRESIN = RESIN SWITCH
```

```
C              = 1 HERCULES 3501-6
C              = 2 SHELL RSL1282/9470 32.4 PHR
C       ICURE  = CUREING SWITCH
C              = 0 CURE CYCLE IS NOT SIMULATED
C              = 1 CURE CYCLE IS SIMULATED
C
C     LINE 3 : RLGTH, WIDTH
C       RLGTH   = LENGTH OF LAMINATE
C       WIDTH   = WIDTH OF LAMINATE
C
C     LINE 4 : TIMEIN, TAUTO  (NTEMPS NUMBER OF LINES)
C       TIMEIN = TIME OF TEMPERATURE CHANGE
C       TAUTO   = TEMPERATURE IN AUTOCLAVE AT TIMEIN
C
C NOTE: IF IVSWH = 0 THEN ADD A LINE HERE WITH VISCFL
C
C     LINE 5: NPLIES, ZETA, DIAFI, RHOFI, TUNCPT, RKCC, PZERO
C       NPLIES = NUMBER OF PLIES OF MATERIAL
C       ZETA   = AREAL WEIGHT OF FABRIC
C       DIAFI  = DIAMETER OF INDIVIDUAL FILLAMENTS
C       RHOFI  = DENSITY OF SOLID MATERIAL
C       TUNCPT = THICKNESS OF UNCOMPACTED PLY
C       RKCC   = KOZENY-CARMEN CONSTANT
C       PZERO  = PRESSURE AT WHICH D = 0 ( PZERO>0 )
C
C     LINE 6: A(J)
C       A(J) = COEFFICIENTS OF THE COMPACTION MODEL
C
C     LINE 7 : POSA, POSB, ATIME, BTIME, CTIME
C          DTIME(MATL)=DTIME(1)+ATIME*POS
C          IF (POS.GE.POSA) DTIME(MATL)=BTIME
C          IF (POS.GE.POSB) DTIME(MATL)=CTIME
C
C       POSA   = THK FRACTION FOR FIRST TIME INCRIMENT HOLD
C       POSB   = THK FRACTION FOR SECOND TIME INCRIMENT HOLD
C       ATIME  = RATE COEFFICIENT OF THE TIME SCHEME
C       BTIME  = FIRST HOLD TIME STEP
C       CTIME  = SECOND HOLD TIME STEP
C
C     LINE 8 : PAUTO, PBAG
C       PAUTO  = PRESSURE IN THE AUTOCLAVE OR APPLIED BY PLATENS
C       PBAG   = PRESSURE IN THE BLEEDER
C
C       NOTE:  ALL PRESSURES IN GAGE
C
C     LINE 9 : NTOOL, NPRESS, IFREQ, IRED
C       NTOOL  = NUMBER OF DIVISIONS IN TOOL PLATE
C       NPRESS = NUMBER OF DIVISIONS IN PRESSURE PLATE
C       IFREQ  = FREQUENCY OF PRINTOUT....WR2 TIME
C       IRED   = FREQUENCY OF PRINTOUT....WR2 POSITION
C
```

```
C     LINE 9 : CPFL, CPFI, KTFL, KTFI, HR
C       CPFL   = SPECIFIC HEAT OF THE RESIN
C       CPFI   = SPECIFIC HEAT OF THE FIBER
C       KTFL   = THERMAL CONDUCTIVITY OF THE RESIN
C       KTFI   = THERMAL CONDUCTIVITY OF THE FIBER
C       HR     = HEAT OF REACTION OF THE RESIN
C
C     LINE 10: DELT, VEL
C       DELZ   = TIME STEP FOR CALCULATION DURING CURE
C       VEL    = HEAT TRANSFER COEFFICIENT
C
C     LINE 11: ZTOOL, KTOOL, RHOTOL, CPTOOL
C       ZTOOL  = THICKNESS OF THE TOOL PLATE
C       KTOOL  = THERMAL CONDUCTIVITY OF THE TOOL PLATE
C       RHOTOL = DENSITY OF THE TOOL PLATE
C       CPTOOL = SPECIFIC HEAT OF THE TOOL PLATE
C
C     LINE 12: ZPRES, KPRES, RHOPRE, CPPRES, NBLEED
C       ZPRES  = THICKNESS OF THE PRESSURE PLATE
C       KPRES  = THERMAL CONDUCTIVITY OF THE PRESSURE PLATE
C       RHOPRE = DENSITY OF THE PRESSURE PLATE
C       CPPRES = SPECIFIC HEAT OF THE PRESSURE PLATE
C       NBLEED = NUMBER OF BLEEDER PLIES
C
C    NOTE: UNITS SHOULD BE IN SI EXCEPT THE COMPACTION COEFFICIENTS.
C        ALL INPUT IS IN FREE FORMAT
C
C=================================
C
C-------------------------------------------------------
C ** MAIN PROGRAM **
C-------------------------------------------------------
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1       KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/ONE/ X(600),Y(600),CENTX(200),CENTY(200)
      COMMON/TWO/ NEQ,IBWTH,STIFF(600,50),RHSV(600)
      COMMON/FIVE/ NOEL,NNODES,NMATR,NTIMES
      COMMON/MATLS/ A(5),COMPP,RLGTH,WIDTH,RVOL,RMASS,
     1             TUNCPT,ZETA,DIAFI,RHOFI,
     2             RKCC,PORO,THK,TEMP,
     3        FRATE,ALPHA,FVISC,GAS,PZERO,IVSWH,IRESIN,NPLIES,ICURE
      COMMON/TIMES/ TIME,DTIME(2),ATIME,BTIME,CTIME,POSA,POSB,ITIME
      DIMENSION ANAME(18),SRHSV(600),ARHSV(600)
      CHARACTER*12 FNDAT,FNLIST,FNIPLT,FNCPLT
C
      WRITE(*,'(A/)') ' ENTER THE INPUT DATA FN.FT'
      READ(*,'(A/)') FNDAT
      WRITE(*,'(A/)') ' ENTER THE LISTING FN.FT'
      READ(*,'(A/)') FNLIST
      WRITE(*,'(A/)') ' ENTER THE INFILTRATION PLOTTING FN.FT'
```

```
      READ(*,'(A/)') FNIPLT
      WRITE(*,'(A/)') ' ENTER THE CURE PLOTTING FN.FT'
      READ(*,'(A/)') FNCPLT
      OPEN(5,FILE=FNDAT,STATUS='OLD')
      OPEN(6,FILE=FNLIST,STATUS='NEW')
      OPEN(7,FILE=FNIPLT,STATUS='NEW')
      OPEN(8,FILE=FNCPLT,STATUS='NEW')
C
      MAXBW=50
C
C ** PROBLEM  IDENTIFICATION  AND  DESCRIPTION **
C
      READ(5,1)   (ANAME(I),I=1,18)
      WRITE (6,7) (ANAME(I),I=1,18)
C
      NTS=1
      ITIME=1
      TEMP=0.0D0
      ALPHA=0.0D0
      TIME=0.0D0
      MAXDOF=600
C
      CALL READIN (ITRUN)
      IF (IVSWH.EQ.1) THEN
        TEMP=FTEMP(TIME,ITIME)
        CALL RESIN(2)
        ALPHA=ALPHA+FRATE*DTIME(2)
        RMASS=RHOFL*RVOL
        WRITE(6,8) RMASS
      END IF
C
C ** BEGIN TIME STEPPING LOOP **
C
      WRITE(6,2)
 55   IF ((X(NNODES).GT.THK+X(7)).OR.(NTS.GT.NTIMES)) GO TO 52
C
C ** CALCULATE THE RESIN TEMPERATURE, VISCOSITY, AND DEGREE OF CURE **
C
      IF (IVSWH.EQ.1) THEN
        TEMP=FTEMP(TIME,ITIME)
        CALL RESIN(2)
        ALPHA=ALPHA+FRATE*DTIME(2)
      END IF
C
C ** COMPUTE  MAX. NODAL DIFF AND BANDWIDTH **
C
      MAXDIF=0
      DO 60 I=1,NOEL
        DO 60 J=1,8
          DO 60 K=1,8
            LL=IABS(NODMAT(I,J)-NODMAT(I,K))
```

```
        IF (LL.GT.MAXDIF) MAXDIF=LL
 60      CONTINUE
C
      IBWTH=MAXDIF+1
      NEQ=NNODES
      IF (IBWTH.GT.MAXBW) GO TO 65
C
      CALL GLOBL (ITRUN)
C
      IF (ITRUN.GT.0) GO TO 50
C
 70   CALL SOLVR
C
 95   CALL STRESS
      POS=(X(NNODES)-X(8))/THK
      WRITE(6,3) TIME,TEMP,POS,ALPHA,VISCFL,VELSTO(NOEL,1)
      WRITE(7,3) TIME,TEMP,POS,ALPHA,VISCFL,VELSTO(NOEL,1)
      CALL RECON
C
      NTS=NTS+1
      GO TO 55
 65   WRITE(6,4) IBWTH,MAXBW
C
      GO TO 55
 52   IF (X(NNODES).GT.THK+X(7)) THEN
       TIME=TIME-DTIME(NODMAT(NOEL,9))
     1       +(THK+X(7)-X(NNODES-7))/VELSTO(NOEL-1,1)
C
       IF (IVSWH.EQ.1) THEN
        TEMP=FTEMP(TIME,ITIME)
        CALL RESIN(2)
        ALPHA=ALPHA+FRATE*DTIME(2)
       END IF
C
       POS=1.0D0
       WRITE(6,3) TIME,TEMP,POS,ALPHA,VISCFL,VELSTO(NOEL-1,1)
       WRITE(7,3) TIME,TEMP,POS,ALPHA,VISCFL,VELSTO(NOEL-1,1)
       WRITE (6,5)
       IF ((IVSWH.EQ.1).AND.(ICURE.EQ.1)) CALL CURE
      END IF
      IF (NTS.GT.NTIMES) WRITE (6,6)
 50   CONTINUE
      STOP
C------------------------------
C ** FORMATS FOR MAIN PROGRAM **
C------------------------------
 1    FORMAT (18A4)
 2    FORMAT(///'  TIME',7X,'TEMP',4X,'POSIT. OF',4X,'DEGREE OF',5X,
     1 'FLUID'/20X,'INFILTRATION',5X,'CURE',4X,'VISCOSITY',
     2 2X,'VELOCITY'///)
 3    FORMAT(7(1PE11.4))
```

```
4   FORMAT (//'**** BANDWIDTH =',I4,' EXCEEDS MAX. ALLOWABLE =',
   1I4//)
5   FORMAT(///' **** INFILTRATION COMPLETE ****'///)
6   FORMAT(///' **** OUT OF TIME ****'///)
7   FORMAT (1X,18A4//)
8   FORMAT(8X,'RESIN MASS . . . . . . .',1PE15.7)
    END
```

7.2 Subroutine READIN

```
C-------------------------------------------------------------------
C ** READS IN DATA AND GENERATES PRELIMINARY MESH **
C-------------------------------------------------------------------
      SUBROUTINE READIN(ITRUN)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1     KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/ONE/ X(600),Y(600),CENTX(200),CENTY(200)
      COMMON/FOUR/ PRESS(600)
      COMMON/FIVE/ NOEL,NNODES,NMATR,NTIMES
      COMMON/MATLS/ A(5),COMPP,RLGTH,WIDTH,RVOL,RMASS,
     1          TUNCPT,ZETA,DIAFI,RHOFI,
     2          RKCC,PORO,THK,TEMP,
     3      FRATE,ALPHA,FVISC,GAS,PZERO,IVSWH,IRESIN,NPLIES,ICURE
      COMMON/TIMES/ TIME,DTIME(2),ATIME,BTIME,CTIME,POSA,POSB,ITIME
      COMMON/TEMPS/ TIMEIN(300),TAUTO(300),NTEMPS
C
      ITRUN=0
      ISTOP=0
      NNODES=8
      NOEL=1
      NMATR=1
      DTIME(1)=1.0D-15
      DTIME(2)=1.0D-15
      FRAC=1.0D0
C
      READ (5,*) NTIMES,NTEMPS,IVSWH,IRESIN,ICURE
C
      WRITE (6,1) NTIMES,NTEMPS,IVSWH,IRESIN,ICURE
C
C ** READS AND PRINTS DATA SPECIFIC TO THE PROBLEM **
C
      READ (5,*)  RLGTH,WIDTH
      WRITE (6,2) RLGTH,WIDTH
C
C ** READS AND PRINTS MATERIAL SPECIFIC DATA **
C
      IF (IVSWH.EQ.0) THEN
       READ(5,*) VISCFL
       WRITE(6,3) VISCFL
      ELSE
       READ(5,*) (TIMEIN(I),TAUTO(I),I=1,NTEMPS)
       WRITE(6,4) (TIMEIN(I),TAUTO(I),I=1,NTEMPS)
       GAS=8.314D-3
      END IF
C
      RPERM(1,1,1)=1.0D0
```

```
      RPERM(1,2,2)=1.0D+0
      RPERM(1,1,2)=0.0D0
      RPERM(1,2,1)=0.D0
C
      READ (5,*) NPLIES,ZETA,DIAFI,RHOFI,TUNCPT,RKCC,PZERO
     1        ,(A(J),J=1,5)
      READ (5,*) POSA,POSB,ATIME,BTIME,CTIME
C
      READ(5,*) PAUTO,PBAG
      COMPP=PAUTO-PBAG
      WRITE(6,8) PAUTO,PBAG,COMPP
C
C ** CALCULATES THE PERMEABILITY TENSOR **
C
      CALL PERM
      WRITE (6,5) NPLIES,ZETA,DIAFI,RHOFI,TUNCPT,
     1       RKCC,PZERO,(A(J),J=1,5)
      WRITE (6,6) ATIME,POSA,BTIME,POSB,CTIME
      WRITE (6,7) THK,PORO,RVOL,RPERM(2,1,1)
C
C ** GENERATE INITIAL MESH **
C
      XMAX=0.D0
      X(1)=0.0D0
      Y(1)=0.0D0
      X(2)=0.0D0
      Y(2)=1.0D0
      X(3)=0.0D0
      Y(3)=2.0D0
      X(4)=1.0D0
      Y(4)=0.0D0
      X(5)=1.0D0
      Y(5)=2.0D0
      X(6)=2.0D0
      Y(6)=0.0D0
      X(7)=2.0D0
      Y(7)=1.0D0
      X(8)=2.0D0
      Y(8)=2.0D0
C
      DO 15 M=1,8
       KSTRG(M)=0
       X(M)=X(M)/2.0D0*THK
 15    Y(M)=Y(M)/2.0D0*THK
C
      NODMAT(1,1)=1
      NODMAT(1,2)=4
      NODMAT(1,3)=6
      NODMAT(1,4)=7
      NODMAT(1,5)=8
      NODMAT(1,6)=5
```

```
      NODMAT(1,7)=3
      NODMAT(1,8)=2
      NODMAT(1,9)=1
C
      NPRESS=6
C
      PRESS(1)=PAUTO
      PRESS(2)=PAUTO
      PRESS(3)=PAUTO
      PRESS(6)=PBAG
      PRESS(7)=PBAG
      PRESS(8)=PBAG
C
      KSTRG(1)=1
      KSTRG(2)=1
      KSTRG(3)=1
      KSTRG(6)=1
      KSTRG(7)=1
      KSTRG(8)=1
C
      RETURN
C-----------------------------------
C ** FORMATS FOR SUBROUTINE READIN **
C-----------------------------------
 1    FORMAT (//' INPUT:'//' PROBLEM PARAMETERS:'//5X,
     1' NUMBER OF TIME STEPS . . . . . . . . . . . . . . . . .',I5/5X,
     2' NUMBER OF TEMPERATURE CHANGES. . . . . . . . . . . .',I5/5X,
     3' VISCOSITY SWITCH ( 1 = TEMP DEPEND, 0 = CONSTANT ) .',I5/5X,
     4' RESIN TYPE . . . . . . . . . . . . . . . . . . . . .',I5/5X,
     5' CURE SWITCH ( 0 = NO CURE, 1 = CURE ). . . . . . . .',I5)
 2    FORMAT (////' MATERIAL CHARACTERISTICS:'////
     1        8X,'LAMINATE LENGTH. . . . .',1PE15.7/
     2        8X,'LAMINATE WIDTH . . . . .',1PE15.7/)
 3    FORMAT (8X,'FLUID VISCOSITY. . . . .',1PE15.7)
 4    FORMAT (////' CHARACTERISTICS OF THE TEMPERATURE PROFILE:'//
     1        8X,'TIME OF TEMP CHANGE',
     2        8X,'AUTOCLAVE TEMP'/2(10X,1PE15.7))
 5    FORMAT (' SOLID PROPERTIES:'//
     1        8X,'NUMBER OF PLIES. . . . .',I5/
     2        8X,'AREAL WEIGHT . . . . . .',1PE15.7/
     3        8X,'DIAMETER OF FIBER. . . .',1PE15.7/
     4        8X,'DENSITY OF FIBER . . . .',1PE15.7/
     5        8X,'UNCOMPACTED THICKNESS. .',1PE15.7/
     6        8X,'KOZENY-CARMEN CONSTANT .',1PE15.7/
     7        8X,'PRESSURE AT ZERO DEFL. .',1PE15.7//
     8        8X,'MATERIAL COEFFICIENTS. .'//10X,5(1PE15.7)///)
 6    FORMAT (' TIME INCRIMENTS:'/
     1        8X,'TIME COEFF A . . . . . .',1PE15.7/
     2        8X,'FIRST HOLD POSITION. . .',1PE15.7/
     3        8X,'TIME COEFF B . . . . . .',1PE15.7/
     4        8X,'SECOND HOLD POSITION . .',1PE15.7/
```

```
     5        8X,'TIME COEFF C . . . . . .',1PE15.7///)
7    FORMAT( ' MATERIAL RESULTS:'/
     1        8X,'LAMINATE THICKNESS . . .',1PE15.7/
     2        8X,'POROSITY . . . . . . . .',1PE15.7/
     3        8X,'TOTAL RESIN VOLUME . . .',1PE15.7/
     4        8X,'PERMEABILITY . . . . . .',1PE15.7/))
8    FORMAT(////' PRESSURES:'/
     1        8X,'AUTOCLAVE PRESSURE . . .',1PE15.7/
     2        8X,'BAG PRESSURE . . . . . .',1PE15.7/
     3        8X,'COMPACTION PRESSURE. . .',1PE15.7//)
     END
```

7.3 Subroutine PERM

```
C--------------------------------------------------------------------
C ** CALCULATES THE MATERIAL PERMEABILITY TENSOR                    **
C--------------------------------------------------------------------
      SUBROUTINE PERM
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1      KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/FIVE/ NOEL,NNODES,NMATR,NTIMES
      COMMON/MATLS/ A(5),COMPP,RLGTH,WIDTH,RVOL,RMASS,
     1           TUNCPT,ZETA,DIAFI,RHOFI,
     2           RKCC,PORO,THK,TEMP,
     3        FRATE,ALPHA,FVISC,GAS,PZERO,IVSWH,IRESIN,NPLIES,ICURE
C
C ** CALCULATES THE DEFORMED THICKNESS **
C
      AREA=6.0D0*6.75D0
      RLNZ=DLOG(PZERO/6895.0D0*AREA)
      DZ=A(1)+RLNZ*(A(2)+RLNZ*(A(3)+RLNZ*(A(4)+RLNZ*A(5))))
C
      RLNP=DLOG(COMPP/6895.0D0*AREA)
      DEFL=A(1)+RLNP*(A(2)+RLNP*(A(3)+RLNP*(A(4)+
     1          RLNP*A(5))))-DZ
      THK=NPLIES*(TUNCPT-2.54D-2*DEFL)
C
C ** CALCULATES POROSITY AND PERMEABILITY **
C
      I=2
      PORO=1.D0-NPLIES*ZETA/THK/RHOFI
      RPERM(I,1,1)=DIAFI**2/RKCC*PORO**3/(1.D0-PORO)**2
      RPERM(I,2,2)=DIAFI**2/RKCC*PORO**3/(1.D0-PORO)**2
      RPERM(I,1,2)=0.0D0
      RPERM(I,2,1)=0.D0
      RVOL=THK*RLGTH*WIDTH*PORO
C
      RETURN
      END
```

7.4 Subroutine RESIN

```
C--------------------------------------------------------------------
C ** CALCULATES THE TEMPERATURE, DEGREE OF CURE, VISCOSITY          **
C--------------------------------------------------------------------
      SUBROUTINE RESIN(I)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1      KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/MATLS/ A(5),COMPP,RLGTH,WIDTH,RVOL,RMASS,
     1            TUNCPT,ZETA,DIAFI,RHOFI,
     2            RKCC,PORO,THK,TEMP,
     3       FRATE,ALPHA,FVISC,GAS,PZERO,IVSWH,IRESIN,NPLIES,ICURE
      COMMON/TIMES/ TIME,DTIME(2),ATIME,BTIME,CTIME,POSA,POSB,ITIME
C
C ** CALCULATES THE DEGREE OF CURE AND RESIN VISCOSITY **
C
      IF (IVSWH.EQ.0) THEN
       TEMP=0.0D0
       RETURN
      ELSE
       IF (IRESIN.EQ.1) CALL H35016
       IF (IRESIN.EQ.2) CALL S1282
       VISCFL=FVISC
      END IF
C
      RETURN
      END
```

7.5 Subroutine FTEMP

```
C----------------------------------------------------------------------
C ** FUNCTION FTEMP
C----------------------------------------------------------------------
      FUNCTION FTEMP(TVAL,I)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/TEMPS/ TIMEIN(300),TAUTO(300),NTEMPS
      IF(TVAL.GT.TIMEIN(I+1)) I=I+1
      IF(I.GE.NTEMPS) GO TO 2
      IF(TVAL.NE.TIMEIN(I)) GO TO 1
      FTEMP=TAUTO(I)
      RETURN
    2 FTEMP=TAUTO(NTEMPS)
      RETURN
    1 FTEMP = TAUTO(I)+(TAUTO(I+1)-TAUTO(I))/
     1       (TIMEIN(I+1)-TIMEIN(I))*(TVAL-TIMEIN(I))
      RETURN
      END
```

7.6 Subroutine H35016

```
C-------------------------------------------------------------------
C ** CALCULATES THE TEMPERATURE, DEGREE OF CURE, AND VISCOSITY OF    **
C **   HERCULES 3501-6                                              **
C-------------------------------------------------------------------
      SUBROUTINE H35016
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1      KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/MATLS/ A(5),COMPP,RLGTH,WIDTH,RVOL,RMASS,
     1           TUNCPT,ZETA,DIAFI,RHOFI,
     2           RKCC,PORO,THK,TEMP,
     3        FRATE,ALPHA,FVISC,GAS,PZERO,IVSWH,IRESIN,NPLIES,ICURE
C
       RHOFL  = 1.26D3
       PREX1  = 3.5019D7
       PREX2  =-3.3571D7
       PREX3  = 3.2665D3
       ACT1   = 8.0788D1
       ACT2   = 7.7918D1
       ACT3   = 5.6647D1
       BRR    = 4.7000D-1
       RMULN1 =-3.0166D1
       VACT1  = 9.0905D1
       VISK   = 1.4100D1
C
      IF (ALPHA.LE.0.3D0) THEN
        RK1=PREX1*DEXP(-ACT1/GAS/(TEMP+273.15))
        RK2=PREX2*DEXP(-ACT2/GAS/(TEMP+273.15))
        FRATE=(RK1+RK2*ALPHA)*(1.D0-ALPHA)*(BRR-ALPHA)
      ELSE
        RK3=PREX3*DEXP(-ACT3/GAS/(TEMP+273.15))
        FRATE=RK3*(1.D0-ALPHA)
      END IF
C
      FVISC=DEXP(RMULN1+VACT1/GAS/(TEMP+273.15)+VISK*ALPHA)
C
      RETURN
      END
```

7.7 Subroutine S1282

```
C------------------------------------------------------------------
C ** CALCULATES THE TEMPERATURE, DEGREE OF CURE, AND VISCOSITY OF   **
C **   SHELL RSL1282/9470 32.4PHR                              **
C------------------------------------------------------------------
      SUBROUTINE S1282
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1       KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/MATLS/ A(5),COMPP,RLGTH,WIDTH,RVOL,RMASS,
     1            TUNCPT,ZETA,DIAFI,RHOFI,
     2            RKCC,PORO,THK,TEMP,
     3         FRATE,ALPHA,FVISC,GAS,PZERO,IVSWH,IRESIN,NPLIES,ICURE
C
      TEMP=TEMP+273.15D0
      RHOFL  =  1.158D3
C
      AA=-1.3119D-5
      B= 0.016357D0
      C=-6.7848D0
      D= 936.8D0
      E=-2.0306D-5
      F= 0.025619D0
      G=-10.7646D0
      H= 1507.694D0
      R=8.314D0
      CAPU=44786.58683D0
      RMUINF=7.56525D-9
      AMU=1076.6816D0
      EMU=16702.90914D0
C
      IF (TEMP.LE.383.0D0) THEN
        RM=0.5776D0
        RN=2.034D0
        A1=50.663D0
        E1=35305.6D0
        A2=292.037D0
        E2=30485.075D0
        RKMU=AMU*DEXP(-EMU/R/TEMP)
        GO TO 20
      END IF
C
      IF (TEMP.LE.408.0D0) THEN
        RM=D+TEMP*(C+TEMP*(B+TEMP*AA))
        RN=H+TEMP*(G+TEMP*(F+TEMP*E))
        A1=50.663D0
        E1=35305.6D0
        A2=292.037D0
```

```
      E2=30485.075D0
      RKMU=AMU*DEXP(-EMU/R/TEMP)
      GO TO 20
     END IF
C
     IF (TEMP.LE.422.0D0) THEN
      RM=D+TEMP*(C+TEMP*(B+TEMP*AA))
      RN=H+TEMP*(G+TEMP*(F+TEMP*E))
      A1=50.663D0
      E1=35305.6D0
      A2=7.6908482D13
      E2=119686.623D0
      RKMU=AMU*DEXP(-EMU/R/TEMP)
      GO TO 20
     END IF
C
     IF (TEMP.LE.450.0D0) THEN
      RM=D+TEMP*(C+TEMP*(B+TEMP*AA))
      RN=H+TEMP*(G+TEMP*(F+TEMP*E))
      A1=4.9876D21
      E1=196823.0D0
      A2=9.0382D0
      E2=15230.7028D0
      RKMU=AMU*DEXP(-EMU/R/TEMP)
      GO TO 20
     END IF
C
 20   RK1=A1*DEXP(-E1/R/TEMP)
     RK2=A2*DEXP(-E2/R/TEMP)
C
     FRATE=(RK1+RK2*ALPHA**RM)*(1.0D0-ALPHA**RN)/60
     FVISC=RMUINF*DEXP(CAPU/R/TEMP+RKMU*ALPHA)
C
     TEMP=TEMP-273.15D0
C
     RETURN
     END
```

7.8 Subroutine GLOBL

```
C------------------------------------------------------------------
C ** COMPUTES THE GLOBAL STIFFNESS MATRIX AND GLOBAL LOAD VECTOR    **
C------------------------------------------------------------------
      SUBROUTINE GLOBL (ITRUN)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1       KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/ONE/ X(600),Y(600),CENTX(200),CENTY(200)
      COMMON/TWO/ NEQ,IBWTH,STIFF(600,50),RHSV(600)
      COMMON/FOUR/ PRESS(600)
      COMMON/FIVE/ NOEL,NNODES,NMATR,NTIMES
      DIMENSION LM(16),Z(8,8),WK(8)
C
      ISTOP=0
      ITRUN=0
C
C ** INITIALIZE OVERALL STIFFNESS MATRIX AND OVERALL LOAD VECTOR **
C
      DO 50 I=1,NEQ
        RHSV(I)=0.0D0
        DO 50 J=1,IBWTH
 50       STIFF(I,J)=0.0D0
C
C ** COMPUTE  ELEMENT  STIFFNESSES AND LOADS **
C
      DO 55 M=1,NOEL
        IF (NODMAT(M,9).GT.0) GO TO 60
        ITRUN=ISTOP+1
        WRITE(6,1) ITRUN
        GO TO 55
 60     CALL ASTIF(M,AREA)
C
        IF (AREA.LE.0.0D0) THEN
          WRITE(6,2) M,AREA
          ITRUN=ISTOP+1
          GO TO 55
        END IF
C
C ** ASSEMBLE STIFF MATRIX AND LOAD VECTOR **
C
        DO 65 I=1,8
          II=NODMAT(M,I)
C
          DO 65 J=1,8
            JJ=NODMAT(M,J)-II+1
            IF(JJ)65,65,70
 70         IF(IBWTH-JJ) 75,80,80
```

```
 75        WRITE(6,3) M
          ITRUN = ISTOP + 1
          GO TO 65
 80        STIFF(II,JJ) = STIFF(II,JJ) + STIF(I,J)
 65        CONTINUE
 55   CONTINUE
C
C ** INTRODUCE BOUNDARY CONDITIONS TO THE STIFFNESS AND RHS **
C
     M = 1
 110  IF (KSTRG(M).GE.0.AND.KSTRG(M).LT.4) GO TO 115
      ITRUN = ISTOP + 1
      WRITE(6,1) ITRUN
      M = M + 1
      GO TO 120
C
C ** NODAL UNKNOWN (NO BOUNDARY CONDITION SPECIFIED) **
C
 115    IF (KSTRG(M).EQ.0) THEN
         M = M + 1
         GO TO 120
       END IF
C
C ** NODAL FLOW RATES SPECIFIED **
C
       IF (KSTRG(M).EQ.2) THEN
         M = M + 1
         ITRUN = 1
         GO TO 120
       END IF
C
C ** NODAL PRESSURES SPECIFIED **
C
       IF ((KSTRG(M).EQ.1).OR.(KSTRG(M).EQ.3)) THEN
         CALL BOUNC(PRESS(M),M)
         M = M + 1
       END IF
C
 120    IF (M.LE.NNODES) GO TO 110
C
     IF (ITRUN.EQ.0) GO TO 95
     WRITE(6,1) ITRUN
 95   RETURN
C-----------------------------------
C ** FORMATS FOR SUBROUTINE GLOBL **
C-----------------------------------
 1    FORMAT (//' **** SOLUTION WILL NOT BE PERFORMED BECAUSE OF',I5,
    1' DATA ERRORS'/)
 2    FORMAT (//' **** ERROR ELEMENT',I5,' HAS THE AREA OF',1PE10.4//)
 3    FORMAT (//' **** BAND WIDTH EXCEEDS ALLOWABLE',I5//)
     END
```

7.9 Subroutine ASTIF

```
C---------------------------------------------------------------------
C ** COMPUTES THE ELEMENT STIFFNESS MATRIX AND ELEMENT LOAD VECTOR   **
C---------------------------------------------------------------------
      SUBROUTINE ASTIF(M,AREA)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1       KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/ONE/ X(600),Y(600),CENTX(200),CENTY(200)
      COMMON/THREE/ XJ,B(2,8),BT(8,2),RN(8)
      COMMON/FOUR/ PRESS(600)
      COMMON/FIVE/ NOEL,NNODES,NMATR,NTIMES
      DIMENSION TT(4),SS(4),R(2,2),TEMP0(2,2),TEMP1(2,8),
     1         TEMP2(8,8)
      DATA  SS/-1.D0,1.D0,1.D0,-1.D0/, TT/-1.D0,-1.D0,1.D0,1.D0/
C
      II=NODMAT(M,1)
      JJ=NODMAT(M,2)
      KK=NODMAT(M,3)
      LL=NODMAT(M,4)
      MM=NODMAT(M,5)
      NN=NODMAT(M,6)
      IJ=NODMAT(M,7)
      IK=NODMAT(M,8)
      MATL  =NODMAT(M,9)
C
C ** ANISOTROPIC PERMEABILITY MATRIX **
C
      R(1,1)=RPERM(MATL,1,1)
      R(1,2)=RPERM(MATL,1,2)
      R(2,1)=RPERM(MATL,2,1)
      R(2,2)=RPERM(MATL,2,2)
C
C ** INITIALIZING FOR THE  B I G  INTEGRATION LOOP **
C
 65   DO 70 I  =  1,8
       DO 70 J  =1,8
 70      STIF(I,J)=0.0D0
C
      AREA=(X(II)-X(MM))*(Y(KK)-Y(IJ))-(X(KK)-X(IJ))*(Y(II)-Y(MM))
      CENTX(M)=(X(II)+X(KK)+X(MM)+X(IJ))/4.0D0
      CENTY(M)=(Y(II)+Y(KK)+Y(MM)+Y(IJ))/4.0D0
C
C ** THE NUMERICAL INTEGRATION LOOP **
C
      DO 75 II  =1,4
C
       S=SS(II)*0.577350269189626D0
```

```
      T=TT(II)*0.577350269189626D0
C
C ** CALCULATE THE B AND BT MATRICIES AT THE GAUSS POINTS **
C
      CALL FINDB(M,S,T)
C
      CALL MULT (R,B,2,2,8,TEMP1)
      CALL MULT (BT,TEMP1,8,2,8,TEMP2)
C
      DO 80 I=1,8
       DO 80 J=1,8
 80        STIF(I,J)=STIF(I,J)+TEMP2(I,J)*XJ
C
 75   CONTINUE
     RETURN
     END
```

7.10 Subroutine FINDB

```
C-------------------------------------------------------------------
C ** DETERMINES THE B MATRIX EVALUATED AT THE POINTS S AND T          **
C-------------------------------------------------------------------
      SUBROUTINE FINDB (M,S,T)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1       KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/ONE/ X(600),Y(600),CENTX(200),CENTY(200)
      COMMON/THREE/ XJ,B(2,8),BT(8,2),RN(8)
      DIMENSION RNCS(8),RNCT(8),RNCX(8),RNCY(8),XX(8),YY(8)
C
      DO 50 I = 1,8
        RNCX(I) = 0.0D0
 50     RNCY(I) = 0.0D0
      XJ = 0.0D0
C
      OMT = 1.0D0-T
      OPT = 1.0D0 + T
      OMS = 1.0D0-S
      OPS = 1.0D0 + S
      TSPT = 2.0D0*S + T
      TSMT = 2.0D0*S-T
      TTPS = 2.0D0*T + S
      TTMS = 2.0D0*T-S
C
C ** SHAPE FUNCTIONS **
C
      RN(1) = 0.25D0*OMS*OMT*(-S-T-1.0D0)
      RN(2) = 0.5D0*(1.0D0-S*S)*OMT
      RN(3) = 0.25D0*OPS*OMT*(S-T-1.0D0)
      RN(4) = 0.5D0*(1.0D0-T*T)*OPS
      RN(5) = 0.25D0*OPS*OPT*(S + T-1.0D0)
      RN(6) = 0.5D0*(1.0D0-S*S)*OPT
      RN(7) = 0.25D0*OMS*OPT*(-S + T-1.0D0)
      RN(8) = 0.5D0*(1.0D0-T*T)*OMS
C
C ** N i , s **
C
      RNCS(1) = 0.25D0*OMT*TSPT
      RNCS(2) = -S*OMT
      RNCS(3) = 0.25D0*OMT*TSMT
      RNCS(4) = 0.5D0*OMT*OPT
      RNCS(5) = 0.25D0*OPT*TSPT
      RNCS(6) = -S*OPT
      RNCS(7) = 0.25D0*OPT*TSMT
      RNCS(8) = -0.5D0*OMT*OPT
C
```

```
C
C ** N i , t **
C
      RNCT(1) = 0.25D0*OMS*TTPS
      RNCT(2) = -0.5D0*OMS*OPS
      RNCT(3) = 0.25D0*OPS*TTMS
      RNCT(4) = -T*OPS
      RNCT(5) = 0.25D0*OPS*TTPS
      RNCT(6) = 0.5D0*OMS*OPS
      RNCT(7) = 0.25D0*OMS*TTMS
      RNCT(8) = -T*OMS
C
      DO 55 I = 1,8
        XX(I) = X(NODMAT(M,I))
 55     YY(I) = Y(NODMAT(M,I))
C
      DO 60 I = 1,8
        DO 60 J = 1,8
 60       XJ = XJ + XX(I)*YY(J)*(RNCS(I)*RNCT(J)-RNCT(I)*RNCS(J))
C
      DO 65 I = 1,8
        DO 65 J = 1,8
          RNCX(I) = RNCX(I) + YY(J)/XJ*(RNCS(I)*RNCT(J)-RNCT(I)*RNCS(J))
 65       RNCY(I) = RNCY(I) + XX(J)/XJ*(RNCT(I)*RNCS(J)-RNCS(I)*RNCT(J))
C
C
      DO 75 I = 1,8
        B(1,I) = RNCX(I)
        B(2,I) = RNCY(I)
        BT(I,1) = RNCX(I)
 75     BT(I,2) = RNCY(I)
C
C
      RETURN
      END
```

7.11 Subroutine BOUNC

```
C----------------------------------------------------------------------
C ** COMPILES THE BOUNDARY CONDITIONS INTO THE KNOWN LOAD VECTOR     **
C----------------------------------------------------------------------
      SUBROUTINE BOUNC (U,N)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/TWO/ NEQ,IBWTH,STIFF(600,50),RHSV(600)
C
      DO 50 M=2,IBWTH
        K=N-M+1
        IF (K.LE.0) GO TO 55
        RHSV(K)=RHSV(K)-STIFF(K,M)*U
        STIFF(K,M)=0.0D0
 55     K=N+M-1
        IF (K.GT.NEQ) GO TO 50
        RHSV(K)=RHSV(K)-STIFF(N,M)*U
        STIFF(N,M)=0.0D0
 50     CONTINUE
C
      STIFF(N,1)=1.0D0
      RHSV(N)=U
C
      RETURN
      END
```

7.12 Subroutine SOLVR

```
C-----------------------------------------------------------------------
C ** SOLVES THE SYSTEM OF EQUATIONS IN HALF-BANDWIDTH STORAGE        **
C-----------------------------------------------------------------------
      SUBROUTINE SOLVR
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/TWO/ NEQ,IBWTH,STIFF(600,50),RHSV(600)
C
      NRS = NEQ-1
      NR =  NEQ
C
      DO 50 N=1,NRS
        M=N-1
        MR= MIN0(IBWTH,NR-M)
        PIVOT= STIFF(N,1)
C
        DO 50 L=2,MR
          C= STIFF(N,L)/PIVOT
          I= M+L
          J=0
C
          DO 55 K=L,MR
            J= J+1
 55         STIFF(I,J)= STIFF(I,J)-C*STIFF(N,K)
C
 50    STIFF(N,L)=C
C
      DO 60 N=1,NRS
        M=N-1
        MR= MIN0(IBWTH,NR-M)
        C=RHSV(N)
        RHSV(N)= C/STIFF(N,1)
C
        DO 60 L=2,MR
          I= M+L
 60       RHSV(I)= RHSV(I)-STIFF(N,L)*C
C
      RHSV(NR)= RHSV(NR)/STIFF(NR,1)
C
      DO 65 I=1,NRS
        N= NR-I
        M= N-1
        MR= MIN0(IBWTH,NR-M)
C
        DO 65 K= 2,MR
          L= M+K
 65       RHSV(N)= RHSV(N)-STIFF(N,K)*RHSV(L)
C
```

```
RETURN
END
```

7.13 Subroutine STRESS

```
C---------------------------------------------------------------------
C ** COMPUTES THE SECONDARY VARIABLES                                **
C---------------------------------------------------------------------
      SUBROUTINE STRESS
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1       KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/ONE/ X(600),Y(600),CENTX(200),CENTY(200)
      COMMON/TWO/ NEQ,IBWTH,STIFF(600,50),RHSV(600)
      COMMON/THREE/ XJ,B(2,8),BT(8,2),RN(8)
      COMMON/FIVE/ NOEL,NNODES,NMATR,NTIMES
      DIMENSION VELO(2),TEMP0(2,8),PERM(2,2),ESOLU(8)
C
      DO 50 M=1,NOEL
        CALL FINDB(M,0.577350269189626D0,0.0D0)
        MATL=NODMAT(M,9)
C
        DO 55 I=1,2
          DO 55 J=1,2
 55         PERM(I,J)=RPERM(MATL,I,J)
C
        CALL MULT (PERM,B,2,2,8,TEMP0)
        DO 60 I=1,8
          II=NODMAT(M,I)
 60       ESOLU(I)=RHSV(II)
        CALL MULT (TEMP0,ESOLU,2,8,1,VELO)
C
        VELO(1)=-VELO(1)/VISCFL
        VELO(2)=-VELO(2)/VISCFL
C
        VELSTO(M,1)=VELO(1)
        VELSTO(M,2)=VELO(2)
C
 50    CONTINUE
C
      RETURN
      END
```

7.14 Subroutine RECON

```
C---------------------------------------------------------------------
C ** RECONFIGURES THE MESH FOR THE NEXT TIME STEP                    **
C---------------------------------------------------------------------
      SUBROUTINE RECON
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1      KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/ONE/ X(600),Y(600),CENTX(200),CENTY(200)
      COMMON/FOUR/ PRESS(600)
      COMMON/FIVE/ NOEL,NNODES,NMATR,NTIMES
      COMMON/MATLS/ A(5),COMPP,RLGTH,WIDTH,RVOL,RMASS,
     1            TUNCPT,ZETA,DIAFI,RHOFI,
     2            RKCC,PORO,THK,TEMP,
     3       FRATE,ALPHA,FVISC,GAS,PZERO,IVSWH,IRESIN,NPLIES,ICURE
      COMMON/TIMES/ TIME,DTIME(2),ATIME,BTIME,CTIME,POSA,POSB,ITIME
C
C ** NEW NODAL POSITIONING **
C
      PI=DACOS(-1.0D0)
      MATL=NODMAT(NOEL,9)
      I=NNODES+1
      J=I+1
      K=J+1
      L=K+1
      M=L+1
C
C ** UPDATEING THE TIME
C
      IF (MATL.GT.1) THEN
        POS=(X(NNODES)-X(8))/THK
        DTIME(MATL)=DTIME(1)+ATIME*POS
        IF (POS.GE.POSA) DTIME(MATL)=BTIME
        IF (POS.GE.POSB) DTIME(MATL)=CTIME
      END IF
      TIME=TIME+DTIME(MATL)
C
      X(I)=X(NNODES-1)+0.5D0*DTIME(MATL)*VELSTO(NOEL,1)
      X(J)=X(I)
      X(K)=X(NNODES-1)+DTIME(MATL)*VELSTO(NOEL,1)
      X(L)=X(K)
      X(M)=X(K)
C
      Y(I)= Y(NNODES-2)
      Y(K)= Y(I)
      Y(M)= Y(NNODES)
      Y(J)= Y(M)
      Y(L)= Y(NNODES-1)
C
```

```
C ** CONNECTIVITY MATRIX OF NEW ELEMENT **
C
     NODMAT(NOEL+1,1)=NNODES-2
     NODMAT(NOEL+1,2)=I
     NODMAT(NOEL+1,3)=K
     NODMAT(NOEL+1,4)=L
     NODMAT(NOEL+1,5)=M
     NODMAT(NOEL+1,6)=J
     NODMAT(NOEL+1,7)=NNODES
     NODMAT(NOEL+1,8)=NNODES-1
     IF (NOEL.EQ.1) MATL=MATL+1
     NODMAT(NOEL+1,9)=MATL
C
C ** MOVING BOUNDARY CONDITIONS **
C
     KSTRG(K)=KSTRG(NNODES-2)
     KSTRG(L)=KSTRG(NNODES-1)
     KSTRG(M)=KSTRG(NNODES)
     KSTRG(NNODES)=0
     KSTRG(NNODES-1)=0
     KSTRG(NNODES-2)=0
     KSTRG(I)=0
     KSTRG(J)=0
C
     PRESS(K)=PRESS(NNODES-2)
     PRESS(L)=PRESS(NNODES-1)
     PRESS(M)=PRESS(NNODES)
C
C ** UPDATING THE SITUATION **
C
     NNODES=NNODES+5
     NOEL=NOEL+1
C
     RETURN
     END
```

7.15 Subroutine MULT

```
C------------------------------------------------------------------
C ** MULTIPLIES TWO TENSORS TO GET A THIRD                        **
C------------------------------------------------------------------
      SUBROUTINE MULT(A,B,L,M,N,C)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(L,M),B(M,N),C(L,N)
C
      DO 50 I=1,L
        DO 50 K=1,N
          SUM=0.0D0
          DO 55 J=1,M
 55         SUM=SUM+A(I,J)*B(J,K)
 50       C(I,K)=SUM
C
      RETURN
      END
```

7.16 Subroutine CURE

```
C-----------------------------------------------------------------------
C ** HEAT TRANSFER AND KINETICS OF THE CUREING RESIN                **
C-----------------------------------------------------------------------
      SUBROUTINE CURE
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 KTZ,KTFL,KTFI,KTZI,MDOT,MULN1,KTOOL,KPRES,
     1   LAMTOL,LAMPRE
      DIMENSION AA(300),B(300),C(300),D(300),U(300),T(300),
     1        CALPHA(300),VISC(300),SAVEM(300),RM(300),
     3        Z(300),ZRATIO(300)
      COMMON NODMAT(200,9),RPERM(10,2,2),VISCFL,RHOFL,
     1      KSTRG(600),STIF(8,8),VELSTO(200,2)
      COMMON/MATLS/ A(5),COMPP,RLGTH,WIDTH,RVOL,RMASS,
     1           TUNCPT,ZETA,DIAFI,RHOFI,
     2           RKCC,PORO,THK,TEMP,
     3       FRATE,ALPHA,FVISC,GAS,PZERO,IVSWH,IRESIN,NPLIES,ICURE
      COMMON/TIMES/ TIME,DTIME(2),ATIME,BTIME,CTIME,POSA,POSB,ITIME
      COMMON/TEMPS/ TIMEIN(300),TAUTO(300),NTEMPS
      DATA BMASS,FRACZ,XMASS,
     1   FRACX,ZB,TMN,FRACT,SAVE/8*0.0D0/
      DATA SAVEM/300*0.0D0/
C
C**  READ DATA SET **
C
      READ(5,*) NTOOL,NPRESS,IFREQ,IRED
      READ(5,*) CPFL,CPFI,KTFL,KTFI,HR
      READ(5,*) DELT,VEL
      READ(5,*) ZTOOL,KTOOL,RHOTOL,CPTOOL,
     1         ZPRES,KPRES,RHOPRE,CPPRES,NBLEED
C
C** CALCULATE CONSTANTS FOR TIME = 0 FOR EACH LAYER **
C
      VFR=PORO
      RHO=RHOFI+(RHOFL-RHOFI)*VFR
      RMF=RHOFL*PORO/(RHOFL*PORO+(1.0D0-PORO)*RHOFI)
      CP=CPFI+(CPFL-CPFI)*RMF
      C1=(1.0D0-VFR)/3.14159D0
      BB=2.0D0*(KTFL/KTFI-1.0D0)
      C2=DSQRT(1.0D0-(BB*BB*C1))
      C3=C2/(1.0D0+BB*DSQRT(C1))
      KTZ=(1.0D0-2.0D0*DSQRT(C1))*KTFL+KTFL/BB*
     1   (3.14159D0-4.0D0/C2*DATAN(C3))
      TDIFF=KTZ/(RHO*CP)
      ITOP=0
      IEDGE=0
      N1=NTOOL+1
      N2=N1+NPLIES
      N3=N1+1
```

```
      N4=NTOOL+NPLIES
      N5=N2+1
      N6=NTOOL+NPLIES+NPRESS
      NTOT=N6+1
      DO 50 I=1,NTOT
   50 T(I)=TEMP
C
C** CALCULATE INITIAL MASS AND AREA OF EACH LAYER **
C
      RMFI=0.4
      AREAZ=RLGTH*WIDTH
      FMI=ZETA*AREAZ
      FMFI=1.0-RMFI
      TMI=FMI/FMFI
      RMI=TMI-FMI
      DELZ=THK/FLOAT(NPLIES)
      ZMIN=DELZ
      AI=-(TDIFF*DELT/(DELZ*DELZ))
      BI=1.0-2.0*AI
      VFFF=FMI/(RHOFI*AREAZ*ZMIN)
      VFRF=1.0-VFFF
      TMNF=RHO*AREAZ*ZMIN
      RMIN=TMNF-FMI
      BRR=0.47
      TMNI=TMI*NPLIES
      BTHICK=FLOAT(NBLEED)*0.2540E-02
      HTCT=VEL
      HTCB=HTCT
C
C** PRINT DATA SET **
C
      WRITE(6,200) CPFL,KTFL,HR
      WRITE(6,205) CPFI,KTFI
      WRITE(6,210) RHO,CP,KTZ
      WRITE(6,211) ZTOOL,RHOTOL,CPTOOL,KTOOL
      WRITE(6,212) ZPRES,RHOPRE,CPPRES,KPRES
      WRITE(6,225) DELT,VEL
      WRITE(6,230) IFREQ,IRED
C
C** CALCULATE VECTORS A,B,C**
C
C** TOOL PLATE**
C
      DELZT=ZTOOL/FLOAT(NTOOL)
      TDIFT=KTOOL/(RHOTOL*CPTOOL)
      LAMTOL=DELT/(DELZT*DELZT)
      CTOOL=2.0*TDIFT*LAMTOL
C
C** AIR/TOOL INTERFACE I=1 **
C
```

```
      C(1) = -CTOOL
C
C** INTERIOR TOOL PLATE  2<I<NTOOL**
C
      DO 10 I = 2,NTOOL
        AA(I) = -TDIFT*LAMTOL
        B(I) = 1.0 + 2.0*(-AA(I))
   10   C(I) = AA(I)
C
C** TOOL PLATE/COMPOSITE INTERFACE I = N1**
C
      CON1 = 2.0*TDIFF*DELT/(DELZ*DELZ)
      CON2 = KTOOL/(CTOOL*DELZT)
      CON3 = KTZ/(CON1*DELZ)
      AA(N1) = -KTOOL/DELZT
      B(N1) = CON2*(1.0 + CTOOL) + CON3*(1.0 + CON1)
      C(N1) = -KTZ/DELZ
C
C** INTERIOR OF COMPOSITE N3<I<N4**
C
      DO 60 I = N1,N2
        CALPHA(I) = ALPHA
   60    VISC(I) = VISCFL
      ZIN = DELZ*NPLIES
      Z(N1) = 0.0D0
      ZRATIO(N1) = 0.0D0
      DO 11 I = N3,N2
        Z(I) = Z(I-1) + DELZ
   11   ZRATIO(I) = Z(I)/ZIN
      DO 65 I = N3,N4
        AA(I) = AI
        B(I) = BI
   65   C(I) = AI
C
C** COMPOSITE/PRESSURE PLATE INTERFACE I = N2**
C
      TDIFP = KPRES/(RHOPRE*CPPRES)
      DELZP = ZPRES/FLOAT(NPRESS)
      LAMPRE = DELT/(DELZP*DELZP)
      CPFLES = 2.0*TDIFP*LAMPRE
      CON4 = 2.0*TDIFF*DELT/(DELZ*DELZ)
      CON5 = KTZ/(CON4*DELZ)
      CON6 = KPRES/(CPFLES*DELZP)
      AA(N2) = -KTZ/DELZ
      B(N2) = CON5*(1.0 + CON4) + CON6*(1.0 + CPFLES)
      C(N2) = -KPRES/DELZP
C
C** INTERIOR PRESSURE PLATEN5<I<N6**
C
      DO 12 I = N5,N6
        AA(I) = -TDIFP*LAMPRE
```

```
      B(I) = 1.0 + 2.0*(-AA(I))
   12   C(I) = AA(I)
C
C** PRESSURE PLATE/AIR INTERFACE I = NTOT
C
      AA(NTOT) = -CPFLES
C
C** INITIALIZE COUNTERS **
C
      ICOUNT = 0
 1000 TIME = TIME + DELT
      ICOUNT = ICOUNT + 1
      IPRINT = 0
C
C** SET TEMPERATURES AT BOUNDARIES **
C
      TAIR = FTEMP(TIME,ITIME)
C
C** COMPUTE VALUE OF VECTORS U AND D **
C
      B(1) = 1.0 + CTOOL*(1.0 + HTCB*DELZT/KTOOL)
      D(1) = CTOOL*HTCB*DELZT*TAIR/KTOOL + T(1)
C
      DO 13 I = 2,NTOOL
   13   D(I) = T(I)
C
      TEMP = T(N1)
      ALPHA = CALPHA(N1)
      CALL RESIN(2)
      U(N1) = RHOFL*VFR*HR*FRATE/CP/RHO
      D(N1) = CON3*U(N1)*DELT + (CON2 + CON3)*T(N1)
C
      DO 14 I = N3,N4
        TEMP = T(I)
        ALPHA = CALPHA(I)
        CALL RESIN(2)
        U(I) = RHOFL*VFR*HR*FRATE/CP/RHO
   14   D(I) = T(I) + U(I)*DELT
C
      TEMP = T(N2)
      ALPHA = CALPHA(N2)
      CALL RESIN(2)
      U(N2) = RHOFL*VFR*HR*FRATE/CP/RHO
      D(N2) = CON5*U(N2)*DELT + (CON5 + CON6)*T(N2)
C
      DO 15 I = N5,N6
   15   D(I) = T(I)
C
      B(NTOT) = 1.0 + CPFLES*(1.0 + DELZP*HTCT/KPRES)
      D(NTOT) = CPFLES*DELZP*HTCT*TAIR/KPRES + T(NTOT)
C
```

```
C** COMPUTE NEW TEMPERATURES **
C
      CALL TRIDAG(1,NTOT,AA,B,C,D,T)
C
C** COMPUTE NEW DEGREE OF CURE AND RESIN VISCOSITY **
C
      DO 20 I=N1,N2
        TEMP=T(I)
        ALPHA=CALPHA(I)
        CALL RESIN(2)
        CALPHA(I)=CALPHA(I)+FRATE*DELT
        VISC(I)=VISCFL
   20 CONTINUE
C
C** PRINT RESULTS EVERY IFREQ TIME STEPS **
C
      IF((ICOUNT/IFREQ)*IFREQ.EQ.ICOUNT) IPRINT=1
      IF(TIME.GE.TIMEIN(NTEMPS)) IPRINT=2
      IF(IPRINT.EQ.0) GO TO 1040
C
C** PRINT RESULTS **
C
      WRITE(6,245) TIME,TAIR
      WRITE(6,250) (I,Z(I),T(I),CALPHA(I),VISC(I),
     1             ZRATIO(I),I=N1,N2,IRED)
      WRITE (6,253) T(1),T(NTOT)
      NASDF=N2-N1
      WRITE(8,251) (TIME,T(I),CALPHA(I),VISC(I),
     1             ZRATIO(I),I=N1,N2,NASDF)
      IF(IPRINT.EQ.2) GO TO 999
      GO TO 1000
C
C** CALCULATE NEW VALUES FOR VECTORS A,B,C,U **
C
C**TOOL PLATE/COMPOSITE INTERFACE I=N1
C
 1040 CON1=2.0*TDIFF*DELT/(DELZ*DELZ)
      CON3=KTZ/(CON1*DELZ)
      B(N1)=CON2*(1.0+CTOOL)+CON3*(1.0+CON1)
      C(N1)=-KTZ/DELZ
C
C** INTERIOR OF COMPOSITE N3<I<N4**
C
      DO 40 I=N3,N4
        AA(I)=-2.0*TDIFF*DELT/(DELZ*DELZ*2.0D0)
        B(I)= 1.0+(2.0*TDIFF*DELT/(DELZ*DELZ))
        C(I)=-2.0*TDIFF*DELT/(DELZ*DELZ*2.0D0)
   40   CONTINUE
C
C** COMPOSITE/PRESSURE PLATE INTERFACE I=N2**
C
```

```
      CON4=2.0*TDIFF*DELT/(DELZ*DELZ)
      CON5=KTZ/(CON4*DELZ)
      AA(N2)=-KTZ/DELZ
      B(N2)=CON5*(1.0+CON4)+CON6*(1.0+CPFLES)
C
      GO TO 1000
C
C** FORMAT STATEMENTS **
C
  200 FORMAT (////8X,'RESIN PROPERTIES'/
     1       ' ',10X,'CP    =',E13.5/
     2       ' ',10X,'KT    =',E13.5/' ',10X,'HR    =',E13.5)
  205 FORMAT (//8X,'FIBER PROPERTIES'/
     1       ' ',10X,'CP    =',E13.5/
     2       ' ',10X,'KT    =',E13.5)
  210 FORMAT (//8X,'PLY PROPERTIES'/
     5       ' ',10X,'RHO   =',E13.5/' ',10X,'CP    =',E13.5/
     6       ' ',10X,'KTZ   =',E13.5)
  211 FORMAT (//8X,'TOOL PLATE PROPERTIES'/
     1       ' ',10X,'THICK =',E13.5/' ',10X,'RHO   =',E13.5/
     2       ' ',10X,'CP    =',E13.5/' ',10X,'KT    =',E13.5)
  212 FORMAT (//8X,'PRESSURE PLATE PROPERTIES'/
     1       ' ',10X,'THICK =',E13.5/' ',10X,'RHO   =',E13.5/
     2       ' ',10X,'CP    =',E13.5/' ',10X,'KT    =',E13.5)
  225 FORMAT (//8X,'PROGRAM CONSTANTS'/
     2       ' ',10X,'DELT  =',E13.5/' ',10X,'VEL   =',E13.5)
  230 FORMAT (//8X,'OPTIONS'/
     1       ' ',10X,'IFREQ =',I4/
     2       ' ',10X,'IRED  =',I4)
  245 FORMAT (////8X,'TIME =',E13.6,5X,'TAIR =',F6.1/
     2       /4X,'I',5X,'Z(I)',9X,'T(I)',7X,
     3       'CALPHA(I)',5X,'VISC(I)',7X,'Z/ZI')
  250 FORMAT (' 'I4,4E13.6,F9.5)
  251 FORMAT (' ',4E14.6,F7.3)
  253 FORMAT (/' ',8X,'TTOOL =',E13.6,5X,'TPLATE =',E13.6)
  999 STOP
      END
```

7.17 Subroutine TRIDAG

```
C--------------------------------------------------------------------
C ** SUBROUTINE TRIDAG                                            **
C--------------------------------------------------------------------
     SUBROUTINE TRIDAG(ISTART,IEND,A,B,C,D,T)
     IMPLICIT REAL*8 (A-H,O-Z)
     DIMENSION A(1),B(1),C(1),D(1),T(1),BETA(300),GAMMA(300)
C
C** CALCULATE VECTORS BETA AND GAMMA **
C
     BETA(ISTART)=B(ISTART)
     GAMMA(ISTART)=D(ISTART)/BETA(ISTART)
     ISP1=ISTART+1
     DO 10 I=ISP1,IEND
     BETA(I)=B(I)-A(I)*C(I-1)/BETA(I-1)
  10 GAMMA(I)=(D(I)-A(I)*GAMMA(I-1))/BETA(I)
C
C** CALCULATE TEMPERATURES **
C
     T(IEND)=GAMMA(IEND)
     LAST=IEND-ISTART
     DO 20 J=1,LAST
     I=IEND-J
  20 T(I)=GAMMA(I)-C(I)*T(I+1)/BETA(I)
     RETURN
     END
```

7.18 Subroutine HCONV

```
C------------------------------------------------------------------------
C   CALCULATES THE CONVECTIVE HEAT TRANSFER COEFFICIENT
C   V=VELOCITY(M/S),PHI=VELOCITY CORRECTION FACTOR
C------------------------------------------------------------------------
      SUBROUTINE HCONV(TT,TB,HT,HB,PCURE,V,XLEN)
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 MUAIR
      TR=((TT-273.)*1.8+32.)+460.
      PSI=PCURE/6894.8
C
C**SPECICIFIC HEAT  (J/KG-K)
      CPAIR=1008.3
C
C**VISCOSITY  (N-SEC/M2)
      MUAIR=490.728E-9*TR**1.5/(TR+198.72)
C
C**THERMAL CONDUCTIVITY  (W/M-K)
      TKAIR=(2.E-5*(TR-460.)+.0133)*1.731
C
C**DENSITY  (KG/M3)
      RHOAIR=1.326*2.03591*PSI/TR*16.02
C
C**REYNOLDS NUMBER
      REL=RHOAIR*V*XLEN/MUAIR
C
C**PRANDTL NUMBER
      PR=CPAIR*MUAIR/TKAIR
      IF(PR.GE..1.AND.REL.LT.500000.) GO TO 316
      IF(PR.LT..1.AND.REL.LT.500000.) GO TO 317
      IF(PR.GE..5.AND.REL.GE.500000.) GO TO 318
      IF(PR.LT..5.AND.REL.GE.500000.) GO TO 319
  316 HT=(1.133*(REL*PR)**.5*PR**.33)*TKAIR/XLEN*PHI
      GO TO 320
  317 HT=(1.133*(REL*PR)**.5)*TKAIR/XLEN*PHI
      GO TO 320
  318 HT=(0.36*PR**.33*(REL**.8-23200.))*TKAIR/XLEN*PHI
      GO TO 320
  319 WRITE(6,321)PR,REL
  321 FORMAT(/,130('*'),/,'THE TOP CONVECTIVE HEAT TRANSFER COEFFICIEN',
     1'T IS OUT OF REALISTIC BOUNDS',' PR=',E10.4,' REL=',E10.4,/,
     2130('*'),/)
  320 CONTINUE
      TR=((TB-273.)*1.8+32.)+460.
      CPAIR=1008.3
      MUAIR=490.728E-9*TR**1.5/(TR+198.72)
      TKAIR=(2.E-5*(TR-460.)+.0133)*1.731
      RHOAIR=1.326*2.03591*PSI/TR*16.02
      XLEN=.305
```

```
      REL=RHOAIR*V*XLEN/MUAIR
      PR=CPAIR*MUAIR/TKAIR
      IF(PR.GE..1.AND.REL.LT.500000.) GO TO 326
      IF(PR.LT..1.AND.REL.LT.500000.) GO TO 327
      IF(PR.GE..5.AND.REL.GE.500000.) GO TO 328
      IF(PR.LT..5.AND.REL.GE.500000.) GO TO 329
  326 HB=(1.133*(REL*PR)**.5*PR**.33)*TKAIR/XLEN*PHI
      GO TO 330
  327 HB=(1.133*(REL*PR)**.5)*TKAIR/XLEN*PHI
      GO TO 330
  328 HB=(0.36*PR**.33*(REL**.8-23200.))*TKAIR/XLEN*PHI
      GO TO 330
  329 WRITE(6,331)PR,REL
  331 FORMAT(/,130('*'),/,'THE BOTTOM CONVECTIVE HEAT TRANSFER ',
     1'COEFFICIENT IS OUT OF REALISTIC BOUNDS',' PR=',E10.4,' REL=',
     2E10.4,/,130('*'),/)
  330 CONTINUE
      RETURN
      END
```

BIBLIOGRAPHIC DATA SHEET	1. Report No. CCMS-89-11, VPI-E-89-14	2.	3. Recipient's Accession Nc
4. Title and Subtitle RTM User's Guide			5. Report Date May 1989
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15. Supplementary Notes

16. Abstracts

RTM is a Fortran '77 computer code which simulates the infiltration of textile reinforcements and the kinetic thermosetting polymer resin systems. The computer code is based on the process simulation model develc by the author [1]. The compaction of dry, woven textile composites is simulated to describe the increase in ! volume fraction with increasing compaction pressure. Infiltration is assumed to follow D'Arcy's law for Newto viscous fluids. The chemical changes which occur in the resin during processing are simulated with a ther kinetics model. The computer code is discussed on the basis of the required input data, output files and s comments on how to interpret the results. An example problem is solved and a complete listing is included.

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17c. COSATI Field/Group

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The Center for Composite Materials and Structures is a coordinating organization for research and educational activity at Virginia Tech. The Center was formed in 1982 to encourage and promote continued advances in composite materials and composite structures. Those advances will be made from the base of individual accomplishments of the forty members who represent ten different departments in two colleges.

The Center functions through an Administrative Board which is elected yearly and a Director who is elected for a three-year term. The general purposes of the Center include:

- collection and dissemination of information about composites activities at Virginia Tech,
- contact point for other organizations and individuals,
- mechanism for collective educational and research pursuits,
- forum and agency for internal interactions at Virginia Tech.

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