# TSTRESS - A Transient Stress Computer Code

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FUSION TECHNOLOGY INSTITUTE

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Fusion Technology Institute
University of Wisconsin
1500 Engineering Drive
Madison, WI 53706

http://fti.neep.wisc.edu

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Robert R. Peterson

Robert D. Watson

Wilhelm G. Wolfer

Gregory A. Moses

Fusion Engineering Program

Nuclear Engineering Department

University of Wisconsin

Madison, Wisconsin 53706

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## I. Introduction

TSTRESS is a one-dimensional inelastic stress analysis code used to calculate the time history of plane stresses in a section of a first wall of a fusion power reactor. The code is applicable to either inertially confined or magnetically confined fusion reactors. TSTRESS computes stresses which are caused by four different sources: 1) membrane loads from internal coolant pressures or pulsed external shock wave overpressures, 2) temperature gradients through the wall caused by either steady-state heat fluxes or pulsed heat fluxes, 3) irradiation induced differential swelling gradients through the wall, and 4) residual stress gradients caused by both thermal and irradiation creep-induced stress relaxation. TSTRESS, then, provides the user with a complete time history of the one-dimensional stress gradients through the first wall of a fusion power reactor.

One of the most important uses of this code is to provide the stress histories which are needed for self-consistent calculations of either fatigue damage or fatigue crack growth of a pre-existent surface flaw. By self-consistent we mean that the physical interrelationships between the mechanical property changes, stress histories and damage accumulation processes are accounted for simultaneously. When the effects of irradiation on fracture toughness (embrittlement) are included, then the coupling of TSTRESS to a fatigue life code will provide the user with a very sophisticated and flexible package for doing integrated lifetime assessments of fusion reactor first walls.

The thin-walled shell element that is used in TSTRESS represents a flat section of the first wall and is assumed to be constrained from bending, but not from expansion. The model is, therefore, applicable to spherically and cylindrically shaped first walls whose radii of curvature are large when compared to the wall thickness.

The computation of the stress distribution and redistribution with time is based, in principle, on the boundary integral method formulated for time dependent plastic deformation. In the present case, however, the boundary integral method reduces to a one-dimensional integration of the plastic strain components through the wall thickness. These integrals are then converted to sums by employing the Simpson rule of numerical integration. As a result, we are able to express the stress rates at a given point as a function of the stresses at all other points through the wall thickness when inelastic deformation takes place. The time evolution of the stress distribution requires then only the numerical integration over time of a system of coupled ordinary differential equations of first order. The basic structure used in TSTRESS, then, is the numerical solution of N coupled initial value problems using Euler's method, with automatic selection of the time step interval.

## II. Theory

In this chapter the two coupled integral equations for the time-independent in-plane stresses $_x(z)$ and $\sigma_y(z)$ are derived. Then, the two integro-differential equations for the time-dependent stress rates $\dot{\sigma}_x(z)$ and $\dot{\sigma}_y(z)$ are derived. These equations are then converted into a coupled set of one-dimensional, first-order, ordinary differential equations and solved numerically in TSTRESS as an initial value problem for the stresses.

The physical model of the first wall which is used in TSTRESS is a thin-walled shell element, as shown in Figure 1. The element is loaded with externally applied in-plane membrane loads $N_x$ and $N_y$. Also, the element is subjected to time-dependent temperature and swelling loads which are assumed to vary only along the z-direction. In addition, the stresses are allowed to

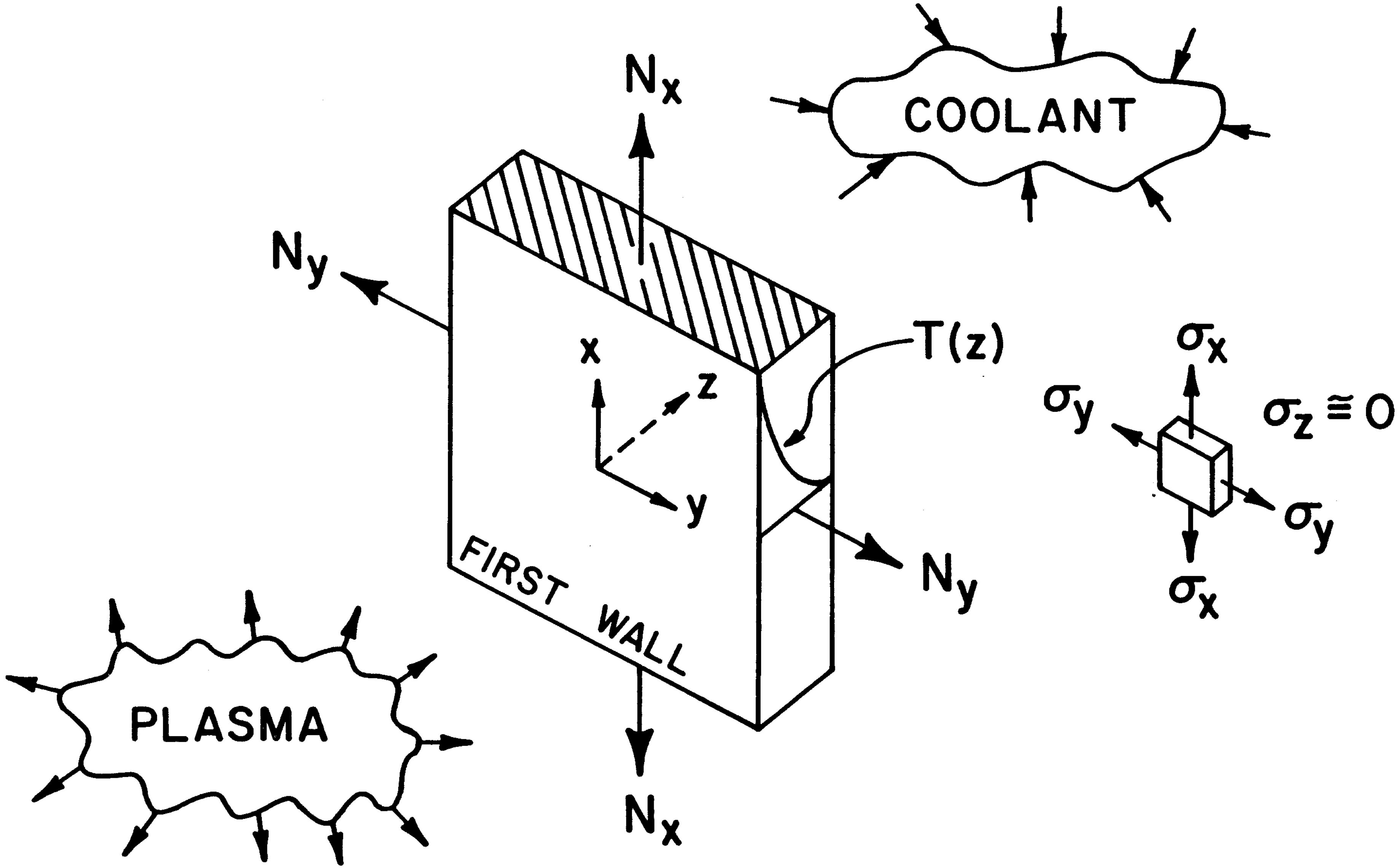


Figure 1 Thin Walled Shell Element Model of First Wall.

relax as a function of time due to the combined influence of thermal and irradiation creep. The elastic properties are temperature dependent and the neutron flux is assumed to remain constant through the wall's thickness. In most first wall designs these assumptions are reasonably well satisfied.

This model can be used to predict the stresses in either tubular first walls, cylindrical modules with ellipsoidal end closures, U-bend cells, or any generally curved thin-walled pressure vessel-type enclosure, so long as the wall's thickness is small when compared to its radius of curvature, namely $h/R \lesssim 0.1$. In this case, the flat plate model shown in Figure 1 is found to be a good approximation for computing stresses. Also, since the normal stress $\sigma_z \cong$-pressure, then it may be neglected because the in-plane stresses $\sigma_x$ and $\sigma_y$ are typically found to be much larger than the internal coolant pressure. This model also assumes that the lateral stress variation over the whole first wall structure is small enough as to not cause a significant change in the radius of curvature and it is also small compared to stress variation through the thickness. This condition requires, then, that the shell element be constrained from bending, and hence, remain flat. It is free to expand in all directions, however.

## IIa. Time-Independent Stress Equation

Based on the model of a first wall as a thin-walled shell element, the equations for time-independent stresses are derived in this section as functions of the inelastic strains and membrane loads. We begin by writing Hooke's law for the three principal stresses:

$$\sigma_x(z) = 2\mu\ (\varepsilon_x - e_x) + \lambda\ (\varepsilon - e) \qquad \text{(II-1)}$$

$$\sigma_y(z) = 2\mu\ (\varepsilon_y - e_y) + \lambda\ (\varepsilon - e) \qquad \text{(II-2)}$$

$$\sigma_z(z) = 2\mu\ (\varepsilon_z - e_z) + \lambda\ (\varepsilon - e) \tag{II-3}$$

where:

$\varepsilon_x, \varepsilon_y, \varepsilon_z$ = total strains

$e_x, e_y, e_z$ = inelastic strains

$\varepsilon = \varepsilon_x + \varepsilon_y + \varepsilon_z$

$e = e_x + e_y + e_z$

$\mu$ = shear modulus

$\lambda = 2\mu\ [\frac{\nu}{1-\nu}]$

$\nu$ = Poisson's ratio .

The inelastic strains are composed of four separate parts, namely:

$$e_x = e_x^{th} + e_x^{ic} + e_x^{tc} + e_x^{sw} \tag{II-4}$$

where:

$e_x^{th}$ = thermal strain

$e_x^{ic}$ = irradiation creep strain

$e_x^{tc}$ = thermal creep strain

$e_x^{sw}$ = swelling strain .

Next, we impose the boundary condition for plane stress, $\sigma_z$=0, and then solve Eqn. (II-3) for $\varepsilon_z$:

$$\varepsilon_z = e_z + \frac{\nu}{1-\nu}\left[e_x + e_y - (\varepsilon_x + \varepsilon_y)\right] . \tag{II-5}$$

Substituting this expression for $\varepsilon_z$ into Eqns. (II-1) and (II-2) then gives:

$$\sigma_x(z) = \frac{2\mu}{1-\nu}(\varepsilon_x - e_x) + \frac{2\mu\nu}{1-\nu}(\varepsilon_y - e_y) \tag{II-6}$$

and,

$$\sigma_y(z) = \frac{2\mu}{1-\nu}(\varepsilon_y - e_y) + \frac{2\mu\nu}{1-\nu}(\varepsilon_x - e_x) . \tag{II-7}$$

As a result of the requirement that the shell element be constrained from bending, the total strains $\varepsilon_x$ and $\varepsilon_y$ <u>cannot</u> be functions of the depth, z, through the wall. Therefore:

$$\varepsilon_x = K_x = \text{constant} \tag{II-8}$$

and

$$\varepsilon_y = K_y = \text{constant} . \tag{II-9}$$

Using this, Eqns. (II-6) and (II-7) can be rewritten as:

$$\sigma_x(z) = \frac{2\mu}{1-\nu}(K_x - e_x) + \frac{2\mu\nu}{1-\nu}(K_y - e_y) \tag{II-10}$$

and,

$$\sigma_y(z) = \frac{2\mu}{1-\nu}(K_y - e_y) + \frac{2\mu\nu}{1-\nu}(K_x - e_x) . \tag{II-11}$$

Next, we write the boundary conditions which are used for static equilibrium:

$$N_x = \int_0^h \sigma_x \, dz \tag{II-12}$$

and,

$$N_y = \int_0^h \sigma_y \, dz \; . \tag{II-13}$$

For the case of a pressurized tube of radius = R and pressure = P, the axial membrane load is given by $N_{axial}$ = PR/2 and the circumferential membrane load is given by $N_{hoop}$ = PR. In a pressurized sphere or hemisphere the membrane loads are equal to each other and are given by $N_x = N_y = PR/2$.

Substituting the stresses, as given by Eqns. (II-10) and (II-11), into the boundary conditions (II-12) and (II-13) gives:

$$\frac{1-\nu}{2\mu} N_x = (K_x + \nu K_y)h - \int_0^h (e_x + \nu e_y)dz \tag{II-14}$$

and,

$$\frac{1-\nu}{2\mu} N_y = (K_y + \nu K_x)h - \int_0^h (e_y + \nu e_x)dz \; . \tag{II-15}$$

After some algebra, these two equations can be solved for $K_x$ and $K_y$:

$$K_x = \frac{N_x - \nu N_y}{2\mu(1+\nu)h} + \frac{1}{h}\int_0^h e_x \, dz \tag{II-16}$$

and,

$$K_y = \frac{N_y - \nu N_x}{2\mu(1+\nu)h} + \frac{1}{h}\int_0^h e_y \, dz \; . \qquad \text{(II-17)}$$

The final step is to substitute these expressions for $K_x$ and $K_y$ into Eqns. (II-10) and (II-11) to give the stress equations

$$\sigma_x(z) = \frac{N_x}{h} + \frac{1}{h}\int_0^h \frac{2\mu}{1-\nu}(e_x + \nu e_y)dz - \frac{2\mu}{1-\nu}(e_x + \nu e_y) \qquad \text{(II-18)}$$

and,

$$\sigma_y(z) = \frac{N_y}{h} + \frac{1}{h}\int_0^h \frac{2\mu}{1-\nu}(e_y + \nu e_x)dz - \frac{2\mu}{1-\nu}(e_y + \nu e_x) \qquad \text{(II-19)}$$

and,

$$\sigma_z = 0 \; . \qquad \text{(II-20)}$$

To calculate the initial elastic stresses in the first wall, caused only by membrane (pressure) loads and temperature gradients in the z-direction, we neglect the swelling and creep strains and define the inelastic strains as simply being:

$$e_x = e_y = e_z = \alpha \Delta T(z) \qquad \text{(II-21)}$$

where:

$$\Delta T(z) = T(z) - T_o$$

$T_0$ = reference temperature where thermal strains vanish

$\alpha$ = coefficient of thermal expansion.

Substituting this into Eqns. (II-18) and (II-19) gives the thermo-mechanical elastic stresses:

$$\sigma_x(z) = \frac{N_x}{h} + \sigma_{th}(z) \qquad \text{(II-22)}$$

and,

$$\sigma_y(z) = \frac{N_y}{h} + \sigma_{th}(z) \qquad \text{(II-23)}$$

where:

$$\sigma_{th}(z) \equiv \frac{1}{h}\int_0^h 2\mu \left(\frac{1+\nu}{1-\nu}\right) \alpha\Delta T dz - 2\mu \left(\frac{1+\nu}{1-\nu}\right) \alpha\Delta T(z) \ . \qquad \text{(II-24)}$$

By using the identity: $2\mu = E/(1+\nu)$, Eqn. (II-24) can be rewritten in a more traditional form:

$$\sigma_{th}(z) = \frac{1}{h}\int_0^h \frac{\alpha E}{(1-\nu)} \Delta T dz - \frac{\alpha E \Delta T(z)}{(1-\nu)} \ . \qquad \text{(II-25)}$$

## IIb. Stress-Rate Equations

The time history of first wall stresses is determined by solving the time-dependent stress-rate equations, which are derived in this section.

We begin by assuming that the wall thickness, h, and the membrane loads, $N_x$ and $N_y$, are independent of time. We also neglect the time-dependence of the elastic constants: $\alpha,\mu,\nu,E$. Using these assumptions, we now take the time derivative of Eqns. (II-18) and (II-19) to get:

$$\dot{\sigma}_x(z) = \frac{1}{h}\int_0^h \frac{2\mu}{1-\nu}(\dot{e}_x + \nu\dot{e}_y)dz - \frac{2\mu}{1-\nu}(\dot{e}_x + \nu\dot{e}_y) \qquad \text{(II-26)}$$

and,

$$\dot{\sigma}_y(z) = \frac{1}{h}\int_0^h \frac{2\mu}{1-\nu}(\dot{e}_y + \nu\dot{e}_x)dz - \frac{2\mu}{1-\nu}(\dot{e}_y + \nu\dot{e}_x) \qquad \text{(II-27)}$$

where:

$$\dot{e}_x = \dot{e}_x(z) \text{ and } \dot{e}_y = \dot{e}_y(z) \ .$$

The next step is to assume a constitutive law for inelastic deformation which describes the inelastic strain rates $\dot{e}_x$ and $\dot{e}_y$ as functions of both the current values of stress, temperature, dose and dose rate, and the previous history of these parameters. We assume, then, that:

$$\dot{e}_x = \alpha\dot{T} + \frac{1}{3}\dot{S} + (\sigma_x - \frac{1}{2}\sigma_y)\ \psi \qquad \text{(II-28)}$$

and,

$$\dot{e}_y = \alpha\dot{T} + \frac{1}{3}\dot{S} + (\sigma_y - \frac{1}{2}\sigma_x)\ \psi \qquad \text{(II-29)}$$

where:

$\dot{S}$ = swelling rate

$$\psi = \text{total creep compliance} .$$

The total creep compliance, $\psi$, is assumed to be the sum of thermal and irradiation creep compliances:

$$\psi = \psi_{thermal} + \psi_{irradiation} . \qquad \text{(II-30)}$$

We now substitute the constitutive Eqns. (II-28) and (II-29) into the stress-rate Eqns. (II-26) and (II-27) to obtain:

$$\begin{aligned} \dot{\sigma}_x(z) = {} & \frac{1}{h} \int_0^h 2\mu \left(\frac{1+\nu}{1-\nu}\right) (\alpha\dot{T} + \frac{1}{3} \dot{S}) dz \\ & - 2\mu \left(\frac{1+\nu}{1-\nu}\right) (\alpha\dot{T} + \frac{1}{3} \dot{S}) \\ & + \frac{1}{h} \int_0^h \frac{\mu\psi}{(1-\nu)} [(2-\nu)\sigma_x - (1-2\nu)\sigma_y] dz \\ & - \frac{\mu\psi}{(1-\nu)} [(2-\nu)\sigma_x - (1-2\nu)\sigma_y] , \end{aligned} \qquad \text{(II-31)}$$

and,

$$\dot{\sigma}_y(z) = \frac{1}{h}\int_0^h 2\mu \left(\frac{1+\nu}{1-\nu}\right) (\alpha\dot{T} + \frac{1}{3}\dot{S})dz \qquad \text{(II-32)}$$

$$- 2\mu \left(\frac{1+\nu}{1-\nu}\right) (\alpha\dot{T} + \frac{1}{3}\dot{S})$$

$$+ \frac{1}{h}\int_0^h \frac{\mu\psi}{(1-\nu)} [(2-\nu)\sigma_y - (1-2\nu)\sigma_x]dz$$

$$- \frac{\mu\psi}{(1-\nu)} [(2-\nu)\sigma_y - (1-2\nu)\sigma_x] .$$

These two coupled differential equations are solved numerically in the computer code TSTRESS as an initial value problem, where the initial stresses are given by Eqns. (II-22) through (II-24).

Eqns. II-31 and II-32 may be transformed into the more convenient forms,

$$\frac{\partial}{\partial t}\sigma(z) = \frac{1}{h}\int_0^h [F(z') + \Psi(z')\,\sigma(z')]\,dz'$$

$$- F(z) - \Psi(z)\,\sigma(z) \qquad \text{(II-33)}$$

and

$$\frac{d\tau(z)}{dt} = \frac{1}{h}\int_0^h \phi(z')\,\tau(z')\,dz' - \phi(z)\,\tau(z) , \qquad \text{(II-34)}$$

where

$$\sigma(z) \equiv \frac{1}{2} [\sigma_x(z) + \sigma_y(z)] \qquad \text{(II-35)}$$

and

$$\tau(z) \equiv \sigma_x(z) - \sigma_y(z) \ . \qquad \text{(II-36)}$$

$\Psi(z)$ and $\phi(z)$ are related to the creep compliance by

$$\Psi(z) = \mu \left(\frac{1+\nu}{1-\nu}\right) \psi(z) \qquad \text{(II-37)}$$

and

$$\phi(z) = 3\mu \ \psi(z) \ , \qquad \text{(II-38)}$$

while $F(z)$ is a function of expansion and swelling,

$$F(z) = \mu \left(\frac{1+\nu}{1-\nu}\right) \{2\alpha \ \dot{T}(z) + \frac{2}{3} \dot{S}(z)\} \ . \qquad \text{(II-39)}$$

## III. Units and Zoning Conventions

TSTRESS uses the following units:

| | | |
|---|---|---|
| Length | -- | cm |
| Time | -- | second |
| Stress | -- | ksi |
| Temperature | -- | Kelvin . |

Finite difference indexing is done using the following conventions:

| | | |
|---|---|---|
| Time indexing: | (n + 3/2) | A |
| | (n + 1) | B |
| | (n + 1/2) | C |
| | (n) | D |
| | (n - 1/2) | E |
| | (n - 1) | F |

Spatial zone indexing:

$$\overset{\bullet}{j-1} \qquad \overset{\bullet}{j} \qquad \overset{\bullet}{j+1}$$

$$j-\tfrac{3}{2} \qquad j-\tfrac{1}{2} \qquad j+\tfrac{1}{2} \qquad j+\tfrac{3}{2}$$

Since there will always be one more zone boundary than there are zones, we start numbering the zone centers at J=2. Quantities measured on the zone boundaries have FORTRAN variable names ending with a 2 while the zone centered quantities are unnumbered.

## IV. Equation of Zone Expansion

The equation of zone expansion is written as

$$\frac{1}{\ell}\frac{d\ell}{dt} = [\alpha \dot{T} + \frac{1}{3} \dot{S}(z)] - \frac{1}{2} \psi(z) \qquad \text{(IV-1)}$$

where $\ell$ is a unit of length along the direction perpendicular to the plane of the plate (the z-direction). $\alpha(z)$ is the coefficient of thermal expansion, $\dot{S}$ the swelling rate and $\psi(z)$ the creep compliance. The temperature is denoted by T.

Eq. IV-1 is solved by converting it into the difference equation,

$$\Delta z_j^n = \Delta z_j^{n-1} \, \Delta t_j^{n-1/2} \, (\alpha_j^n \, \dot{T}_j^n + \frac{1}{3} \dot{S}_j^n - \psi_j^n) + \Delta z_j^{n-1} \; . \qquad \text{(IV-2)}$$

Here, $\Delta z_j^n$ is the width of the j'th zone at time $t^n$ and $\Delta t_j^{n-1/2}$ is the difference between $t^n$ and the time when quantities were most recently calculated. This code has an option where quantities are calculated more frequently in zones that undergo changes in certain parameters most rapidly so that $\Delta t_j^{n-1/2}$ may be different for each zone.

The width of each zone and the total thickness of the plate h are calculated using Eqn. IV-2 in subroutine WIDTH with the thermal expansion coefficient coming from subroutine TPROP. The swelling rate $\dot{S}_j^n$ is found in subroutine SWELL and the creep rate in subroutine CREEP.

V. Stress Rate Equations

Eqns. II-33 and II-34 are solved by converting them to the difference equations,

$$\sigma_j^{n+1/2} = \Delta t_j^n \{\frac{1}{h^n} \sum_j [F_j^n + \Psi_j^n \sigma_j^{n-1/2}] \Delta z_j^n$$

$$- F_j^n - \Psi_j^n \sigma_j^{n-1/2}\} + \sigma_j^{n-1/2} \qquad \text{(V-1)}$$

and

$$\tau_j^{n+1/2} = \Delta t_j^n [(\frac{1}{h^n} \sum_j \phi_j^n \Delta z_j^n \tau_j^{n-1/2})$$

$$- \phi_j^n \tau_j^{n-1/2}] + \tau_j^{n-1/2} . \qquad \text{(V-2)}$$

Eqns. V-1 and V-2 are solved in subroutine STRESS while $F_j^n$ is calculated in subroutine SWELL and $\Psi_j^n$ and $\phi_j^n$ are calculated in subroutine CREEP. Properties of the material, $\alpha$, $\mu$, and $\nu$ are determined in TPROP.

## VI. Temperatures

The temperature in each zone is calculated at each time step in one of two ways. Whichever way is chosen, the temperatures are calculated in subroutine TEMP.

The first way is to interpolate on a grid of temperatures read from an input file in the subroutine INIT. The grid is in position and time and the size and spacings are automatically set to that of the input data. This input data is read in as sets of temperatures at up to 50 points in space, each set corresponding to a different time. The time corresponding to each such set of temperatures is found in the second element of a 10 element parameter vector called WSCAL, which precedes each set of temperatures in the input file. Following all of the sets of temperatures WSCAL is read from the input file again. Here WSCAL(1)<0 is a flag informing TSTRESS that the end of the temperatures has been reached and the positions for the temperatures are then read in. These times and positions are unrelated to the grid of times and positions that TSTRESS uses, so that to find the temperature at the zone boundary at position $x_{j+1/2}$ and time $t^n$, a standard bilinear interpolation is used. The temperature of the zone center is then found by averaging the temperatures at the zone boundaries. The time derivatives of the temperature are also provided at each zone center.

The second method of determining the zone center temperatures is to just use a time independent linear profile. TSTRESS is told to use this method by the setting of the parameters LINEAR=1 and IRDTMP=1. Other input parameters are TFRONT and TBACK, which are the temperatures at the front and back of the plate, respectively. Of course, if this option is used, the time derivatives of the temperatures are zero.

## VII. Conservation of Membrane Load Check

In the model we have chosen, the membrane loads in the x and y directions,

$$N_x = \int_0^h \sigma_x(z',t)\ dz' \qquad \text{(VII-1)}$$

and

$$N_y = \int_0^h \sigma_y(z',t)\ dz' \qquad \text{(VII-2)}$$

are constants in time or else given. This conservation of membrane load is tested in subroutine SCHECK by comparing $N_x$ and $N_y$ calculated using the current stresses with the originally specified values of $N_x$ and $N_y$.

Normally these membrane loads are zero initially but if non-zero membrane loads are desired, this may be accomplished in subroutine INITS.

If it occurs that the membrane loads at some cycle deviate from those calculated initially, SCHECK includes an option allowing the stresses to be adjusted so that conservation of membrane load is preserved. This option is used when the input parameter IADJ≠1 and it works by changing each stress by a small amount so that the membrane load never deviates from its original value:

$$\sigma_{x_j}^{n+1/2} = \sigma_{x_j}^{n+1/2} + \frac{N_x}{h^{n+1/2}} - \frac{1}{h} \sum_i \sigma_{x_i}^{n+1/2}\ \Delta z_i^{n+1/2} \qquad \text{(VII-3)}$$

and

$$\sigma_{y_j}^{n+1/2} = \sigma_{y_j}^{n+1/2} + \frac{N_y}{h^{n+1/2}} - \frac{1}{h} \sum_i \sigma_{y_i}^{n+1/2} \Delta z_i^{n+1/2} . \qquad \text{(VII-4)}$$

Here $N_x$ and $N_y$ are the membrane loads at the start of the calculation.

## VIII. Time Step Control

After each cycle the time step for the next cycle is determined so that a set of stability and accuracy constraints are maintained. This is determined by

$$\Delta t_j^{n+1} = \text{Min} \begin{cases} \text{TGROW* } \Delta t_j^n \\ \text{DTMAX} \\ \Delta t_j^n/\text{RTEMP} \\ \text{DTPULS (during the temperature pulse)} \end{cases} \quad \text{(VIII-1)}$$

for cycles after cycle number NEARLY, or

$$\Delta t_j^{n+1} = \text{DTEAR} \quad \text{(VIII-2)}$$

for the first NEARLY cycles. Here RTEMP is a measure of the stability and accuracy of the previous cycle,

$$\text{RTEMP} = \text{MAX} \begin{cases} |2(\sigma_{x_j}^{n+1/2} - \sigma_{x_j}^{n-1/2})/(\{\sigma_{x_j}^{n+1/2} + \sigma_{x_j}^{n-1/2}\} \text{ TGSIG})| , \\ |2(\sigma_{y_j}^{n+1/2} - \sigma_{y_j}^{n-1/2})/(\{\sigma_{y_j}^{n+1/2} + \sigma_{y_j}^{n-1/2}\} \text{ TGSIG})| , \\ |2(\Delta z_j^n - \Delta z_j^{n-1})/(\{\Delta z_j^n + \Delta z_j^{n-1}\} \text{ TGZ})| , \\ |2(T_j^n - T_j^{n-1})/(\{T_j^n + T_j^{n-1}\} \text{ TGT})| , \\ \text{RCMIN} . \end{cases}$$

(VIII-3)

In the above, DTMAX is the maximum time step, TGROW is the maximum allowable fractional growth in the time step, DTPULS is the maximum time step during the temperature pulse and DTEAR is the early time step. TSIG, TGZ and TGT are the maximum allowable fractional changes in stress, zone widths and temperatures, respectively.

This prescription for finding the time step for the next cycle is followed in subroutine TIMING.

## IX. Zone Skipping

To avoid unnecessary calculation, TSTRESS has the option of not calculating zone properties for every zone on every time step. The integer variable CALC(J) records which zones are to be calculated on the current time step. If CALC(J)=0, zone J is calculated; if CALC(J)=1, quantities in zone J are not changed from their previous values on the current cycle. The value of CALC(J) is calculated at the start of each time step in subroutine TSORT. TSORT uses the following criteria for finding CALC(J):

$$\text{CALC(J)} = 0 \text{ if } \quad \begin{array}{c} t^n - \text{TLAST(J)} > \Delta t_j^n \\ \text{or} \\ n - n' \geq \text{NWAIT} \end{array}$$

otherwise, CALC(J)=1. Here TLAST(J) is the time of the last calculation for this zone and n' is the cycle number of the last calculation for this zone.

## X. Computer Code Description

The TSTRESS code is written in FORTRAN to be run on any main frame computer. A schematic flow chart of TSTRESS is shown in Figure 2.

### Variables

All real variables are implicit double precision. To be consistent, all real constants must be specified in the D notation (i.e. 1.DO). All variables necessary for the computation are contained in named common blocks. The variables are grouped so that a subroutine will have to call upon a small fraction of all of the commons. We now list all of the variables by common block. In the tables below, * indicates that the variable has a default value and ** indicates that it must be set to start the calculation.

### Common Blocks

COMMON/CNTRL/

| | |
|---|---|
| NCYCLE | Current cycle number |
| JMAX** | Number of zones |
| JMAXM1 | JMAX-1 |
| JMAXP1 | JMAX+1 |
| NMAX | Maximum number of cycles |
| NCYC(53) | Number of times each zone has been calculated |
| CALC(53) | Flag for calculation in each zone |
| TGSIG* | Maximum allowable change in stresses on a cycle |
| TGT* | Maximum allowable change in temperature on a cycle |
| IOUT(20)* | Standard output frequencies |
| IVIEW(50)* | Optional output frequencies |
| IOBIN(5)* | Binary output frequencies |

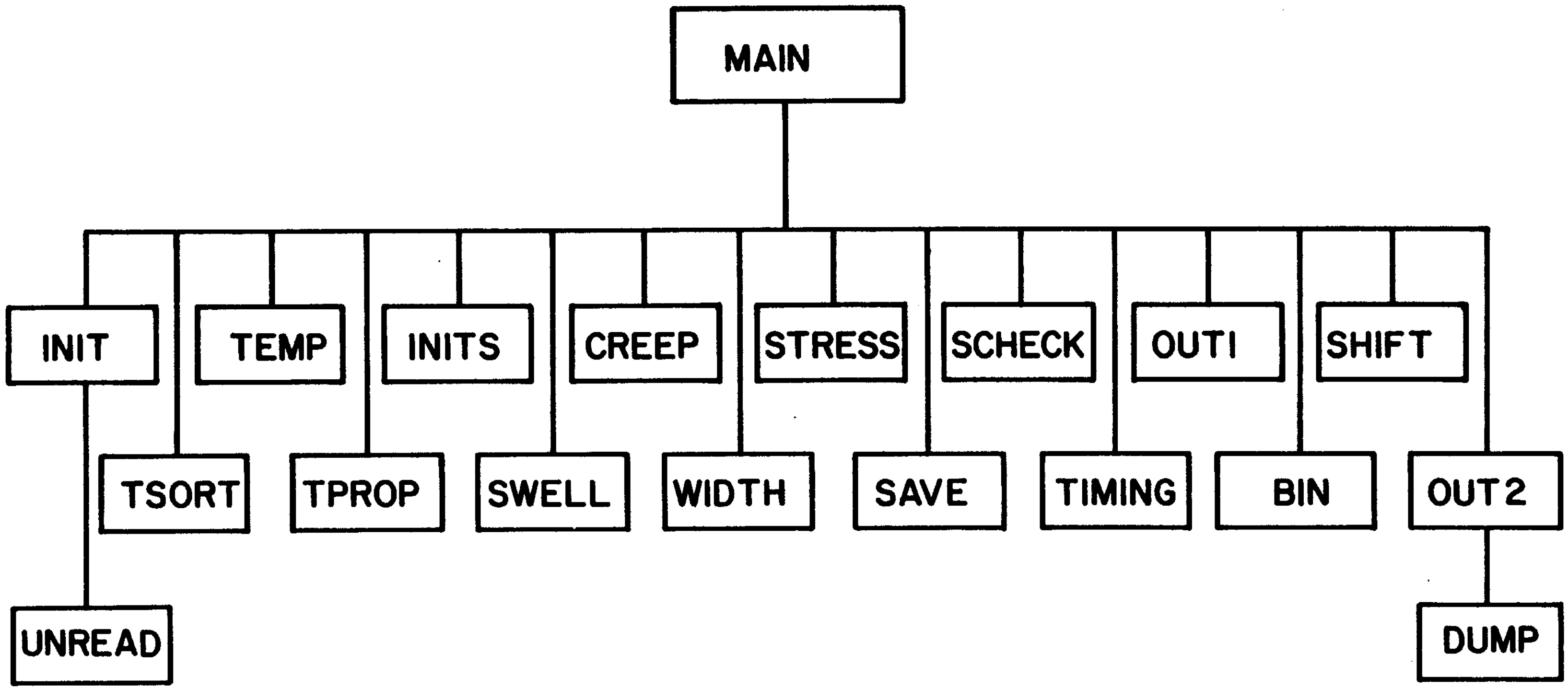


Figure 2 Schematic Flow Chart for TSTRESS

| | |
|---|---|
| JSIG* | Zone number of binary output stress |
| CON(50)* | Constants used in calculation |
| NWAIT* | Maximum number of cycles between calculation cycles for any zone |
| ICOND(53) | Time step limiting condition for each cycle |
| NEARLY* | Number of "early" cycles where time step is DTEAR |
| INMAX | Number of spatial zones in input mesh of temperatures |
| MMAX* | Number of times in input mesh of temperatures |
| JCOND | Zone which determines time step for whole cycle |
| ICOND1(53) | Limiting conditions for each zone |
| ICOND2(53) | |
| KCOND1 | Limiting conditions for whole cycle |
| KCOND2 | |
| ICOUNT(53) | Number of cycles since last calculation for each zone |
| TGZ* | Maximum allowable change in zone width on a cycle |
| IADJ* | Readjustment flag |
| RCMIN* | Minimum change ratio |
| TGROW* | Largest allowable fractional growth in time step |
| IMAXP1 | INMAX+1 |
| TGRDP* | Width of temperature pulse |
| DTPULS* | Maximum time step during temperature pulse |
| IRST* | Restart flag |

| | |
|---|---|
| IRDTMP* | Read in temperature flag |
| COMMON/COEF/ | |
| MUD(53) | $\mu_j^n$ shear modulus for each zone |
| ALFD(53) | $\alpha_j^n$ expansion coefficient for each zone |
| NUD(53) | $\nu_j^n$ Poisson's ratio for each zone |
| CAPFD(53) | $F_j^n$ |
| PSID(53) | $\psi_j^n$ |
| SDOTD(53) | $\dot{S}_j^n$ |
| DPADOT** | DPA rate |
| CPSID(53) | $\Psi_j^n$ |
| PHID(53) | $\phi_j^n$ |
| COMMON/CORE/ | |
| MSTRXC | $N_x^{n+1/2}$ x-component of membrane load at time $t^{n+1/2}$ |
| MSTRXO* | $N_x^{1/2}$ x-component of membrane load at time 0 |
| MSTRYC | $N_y^{n+1/2}$ |
| MSTRYO* | $N_y^{1/2}$ |
| COMMON/LENGTH/ | |
| LTEMPE | Number of single precision words in common block TEMPE |
| LCNTRL | Number of single precision words in common block CNTRL |
| LSTRES | Number of single precision words in common block STRES |
| LCOEF | Number of single precision words in common block COEF |

| | |
|---|---|
| LTIME | Number of single precision words in common block TIME |
| LSAVEV | Number of single precision words in common block SAVEV |
| LCORRE | Number of single precision words in common block CORRE |
| COMMON/SAVEV/ | |
| NSAVE | Number of saved cycles |
| SSAVE(100) | Saved stresses |
| TSAVE(100) | Saved times |
| HSAVE(100) | Saved thicknesses |
| SMXTOT | Maximum x-component of stress in times up to present |
| SMYTOT | Maximum y-component of stress in times up to present |
| TMXTOT | Time of maximum x-component of stress up to present |
| TMYTOT | Time of maximum y-component of stress up to present |
| JMXTOT | Zone of maximum x-component stress up to present |
| JMYTOT | Zone of maximum y-component of stress up to present |
| COMMON/STRES/ | |
| XD(53) | $z^n$ positions of zone centers |
| XF(53) | $z^{n-1}$ |
| SIGXC(53) | $\sigma_{xj}^{n+1/2}$ |

| | |
|---|---|
| SIGXE(53) | $\sigma_{xj}^{n-1/2}$ |
| SIGYC(53) | $\sigma_{yj}^{n+1/2}$ |
| SIGYE(53) | $\sigma_{yj}^{n-1/2}$ |
| SIGC(53) | $\sigma_{j}^{n+1/2}$ |
| SIGE(53) | $\sigma_{j}^{n-1/2}$ |
| TAUC(53) | $\tau_{j}^{n+1/2}$ |
| TAUE(53) | $\tau_{j}^{n-1/2}$ |
| HD | $h^n$ thickness at time $t^n$ |
| HF | $h^{n-1}$ thickness at time $t^{n-1}$ |
| DELHD | Change in thickness on time step n |
| MAXJX | Zone of maximum x-component of stress during present cycle |
| MAXJY | Zone of maximum y-component of strss during present cycle |
| SMAXX | Maximum x-component of stress during present cycle |
| SMAXY | Maximum y-component of stress during present cycle |
| DZD(53)** | $\Delta z_j^n$ |
| DZF(53) | $\Delta z_j^{n-1}$ |
| XD2(53) | Positions of zone boundaries at time $t^n$ |
| COMMON/TEMPE/ | |
| TZONE(50) | Spatial positions of input temperatures |
| TEMP1(50,20) | Input temperatures on input zone boundaries |
| TEMP2D(53) | $T_j^n$ |
| TDOTD(53) | $\dot{T}_j^n$ |
| TTIME(20)* | Times of input temperatures |

| | |
|---|---|
| TDOTM | Maximum $\dot{T}$ |
| MAXJTD | Zone of maximum $\dot{T}$ |
| TEMP2F(53) | $T_j^{n-1}$ |
| LINEAR* | Linear temperature profile flag |
| TFRONT | Temperature at front of plate in linear profile |
| TBACK | Temperature at back of plate in linear profile |
| TEMP2(50) | Input temperature at input zone centers |
| COMMON/TIME/ | |
| TA | $t^{n+3/2}$ |
| TB | $t^{n+1}$ |
| TC | $t^{n+1/2}$ |
| TD* | $t^{n}$ |
| TE | $t^{n-1}$ |
| DTB(53) | $\Delta t_j^{n+1}$ |
| DTC(53) | $\Delta t_j^{n+1/2}$ |
| DTD(53) | $\Delta t_j^{n}$ |
| DTE(53) | $\Delta t_j^{n-1/2}$ |
| DTEAR* | Time step for cycles in the first NEARLY |
| DTMAX* | Maximum allowable time step |
| TMAX* | Maximum time |
| TLAST(53) | Most recent time each zone was calculated |
| DTMIN | Minimum time step |
| DTCYC | Time step for the cycle (minimum of $\Delta t_j^{n+1}$) |
| DTF(53) | $\Delta t_j^{n-1}$ |

Subroutines

| | |
|---|---|
| BIN | Writes results into a binary file in unit 9 |
| CREEP | Calculates the creep compliance $\psi_j^n$ and the functions $\Psi_j^n$ and $\phi_j^n$ |
| DUMP | Writes the common blocks onto unit 20 for use in a restart |
| INIT | Initializes variables, calls UNREAD, sets default values, reads in changes to variables and prints out all of the initial parameters and headings |
| INITS | Sets the initial stresses and membrane loads |
| OUT1 | Prints out results at cycles determined by IOUT(20) |
| OUT2 | Prints out a final summary of results, calls DUMP and writes final parameters onto unit 9 |
| SAVE | Finds and saves the maximum stresses and changes in temperature |
| SCHECK | Computes the membrane loads, compares them with the initial values and has the option of correcting the stresses to give the proper membrane loads |
| SHIFT | Moves all of the variables into the next time step |
| STRESS | Calculates the stresses $\sigma_j^{n+1/2}$ , $\tau_j^{n+1/2}$ , $\sigma_{xj}^{n+1/2}$ and $\sigma_{yj}^{n+1/2}$ |
| SWELL | Calculates the swelling rates $\dot{S}_j^n$ |

| | |
|---|---|
| TEMP | Calculates the temperatures $T_j$ and $\hat{T}_j^n$ from the input temperatures, the positions $z^n$ and the time $t^n$ |
| TIMING | Calculates the time steps $\Delta t_j^{n+1}$ , $\Delta t_j^{n+1/2}$ and $\Delta t^{n+1}$ and the times $t^{n+1}$ and $t^{n+1/2}$ |
| TPROP | Calculates the thermal properties $\nu_j^n$ , $\alpha_j^n$ and $\mu_j^n$ |
| TSORT | Determines which zones will be calculated on this cycle |
| UNREAD | Reads in the common blocks from unit 21 during a restart |
| WIDTH | Calculates $\Delta z_j^n$ and $h^n$ |

Input/Output Units

The TSTRESS code uses 4 different I/O units. These units are listed along with their specific functions.

| Unit # | Function |
|---|---|
| 4 | TSTRESS reads input temperature from this unit |
| 9 | TSTRESS writes binary output for plotting and use in other programs onto this unit |
| 20 | TSTRESS writes out the common blocks at the end of the problem onto this unit for use in a restart |

| | |
|---|---|
| 21 | TSTRESS reads the common blocks from this unit at the beginning of a restart. |

Storage Requirements and Execution Time

TSTRESS requires about 20 K words of core storage on a UNIVAC 1180 computer and uses about 1 msec of CPU time for each zone cycle.

Adding Variables to TSTRESS

When adding a variable to a TSTRESS common block, the common block length must be changed. These lengths are set in subroutine INIT and they are used when one uses the subroutines DUMP and UNREAD to write and read the common blocks. Those lengths are the number of single precision words in each common block. Because the structure of words changes from computer to computer, care must be taken if TSTRESS is used on machines other than UNIVAC 1180's.

## XI. Input Manual

The TSTRESS code reads the namelist input, &BEGIN, from I/O unit 5. The variables and constants that must be inputted are listed in Table XI-1. Those with default values, which must be inputted only if they need to be changed, are given in Table XI-2. Optional output variables are described in Table XI-3.

Table XI-1

Required Input Variables and Constants

| | Default | Description |
|---|---|---|
| NMAX | --- | Number of cycles |
| JMAX | --- | Number of zones |
| DPADOT | --- | DPA rate |
| DZD(J) | --- | Zone widths |
| IOUT(20) | --- | Output frequencies |
| additionally if LINEAR=1 and IRDTMP=1 | | |
| TFRONT | --- | Temperature at front of plate |
| TBACK | --- | Temperature at back of plate |

Table XI-2

Optional Input Variables and Constants

| | Default | Description |
|---|---|---|
| TGSIG | 0.05D0 | Allowable fractional change in stresses over a cycle |
| TGZ | 0.05D0 | Allowable fractional change in zone widths over a cycle |
| TGT | 0.05D0 | Allowable fractional change in temperatures over a cycle |
| TGROW | 1.5D0 | Allowable fractional growth in time step over a cycle |
| RCMIN | 1.D-18 | Minimum ratio of expected change in values to present values |
| IOBIN(1) | 100 | Binary output frequencies |
| IOBIN(2) | 100 | Binary output frequencies |
| JSIG | 1 | Binary output stress zone |
| NWAIT | 10 | Maximum number of cycles a zone may wait between calculations |
| NEARLY | 10 | Number of "early" cycles |
| IADJ | 1 | If IADJ≠1, adjust stresses to conserve membrane loads |

| | | |
|---|---|---|
| LINEAR | 0 | If LINEAR=1, a linear time independent temperature profile is used (even if IRDTMP=0) |
| IRDTMP | 0 | If IRDTMP=0, temperatures are read in from unit 4 |
| MSTRXO | 0.DO | Initial $N_x$ |
| MSTRYO | 0.DO | Initial $N_y$ |
| IRST | 0 | Restart flag |
| MMAX | 1.D-1 | TTIME(MMAX) is temperature pulse period |
| 1VIEW(1-50) | 0 | Optional output frequencies |
| CON(1-50) | 0.DO | Constants (unused) |
| NCYCLE | 1 | First cycle number of problem |
| DTEAR | 1.D-12 | Early time step |
| TD | 1.D-18 | Initial time step |
| TMAX | 1.DO | Maximum time |
| DTMAX | 1.D-3 | Maximum time step |
| DTCYC | DTEAR | Time step of first cycle |
| TGRDP | 1.D-4 | (See TIMING) |
| DTPULS | 1.D-4 | (see TIMING) |
| CALC(J) | 0 | Calculation switch |
| SIGXE(J) | 0.DO | Initial $\sigma_{xj}$ |
| SIGYE(J) | 0.DO | Initial $\sigma_{yj}$ |
| SIGE(J) | 0.DO | Initial $\sigma_j$ |
| TAUE(J) | 0.DO | Initial $\tau_j$ |
| TEMP1 | --- | Input temperatures |

| | | |
|---|---|---|
| TZONE | --- | Spatial positions of TEMP1 |
| INMAX | --- | Number of points in TZONE |

Table XI-3

Optional Output Frequencies IVIEW(I)

| I | Subroutine | Variables Printed |
|---|---|---|
| 1 | TIMING | TB,TC,DTCYC |
| 2 | TIMING | NCYCLE,ICOND,ICOND2,JCOND, KCOND1,KCOND2 |
| 3 | TSORT | NCYCLE,TD,TLAST,DTD,CALC |
| 4 | STRESS | NCYCLE,CAPFD,CPSID,PSID,SIGC, TAUC |
| 5 | TEMP | NCYCLE,INDT,DUMTD,FRACT,XD, IPTEMP,TEMP1,TEMP2D,TDOTD |
| 6 | SWELL | NCYCLE,DPADOT,TD,TEMP2D,R, FNOT,ALPHA,SDOTD |
| 7 | INITS | DUMS,MSTRXC,MSTRYO,HD,ALFD, NUD,MUD,DZD,SIGXE,SIGYE |

## XII. Sample Problem

We have tested the accuracy of TSTRESS by running a sample problem which has a known analytic result. This problem serves as both an example of how to use the code and as a verification of the code. This test problem involves the creep relaxation of a linear residual stress distribution across a flat plate. There are no membrane forces imposed ($N_x$=0,$N_y$=0) and swelling and irradiation creep are ignored. The creep law chosen is for thermal creep and given by

$$\dot{\varepsilon}^{c}_{eq} = A\ \sigma^{4}_{eq} \qquad \text{(XII-1)}$$

where

$$\sigma_{eq} = (\sigma_x^2 + \sigma_y^2 - \sigma_x\ \sigma_x)^{1/2} \qquad \text{(XII-2)}$$

and

$$A = 1.5 \times 10^{-14}\ hr^{-1} - ksi^{-4}\ .$$

The initial linear residual stress profile is established by imposing a time independent linear temperature profile across the plate. This is done by setting LINEAR=1 and IRDTMP=1. The initial stresses are then

$$\sigma_x = \sigma_y = \frac{2\alpha(1+\nu)\mu\Delta T}{(1-\nu)h}\ (z - \frac{h}{2}) \qquad \text{(XII-3)}$$

where $\Delta T$ is the temperature difference across the plate.

As time advances the stresses for this problem may be written exactly as

$$\sigma_x(z,t) = [3BAt + \sigma_x^{-3}(z,t=0)]^{-1/3} \qquad \text{(XII-4)}$$

and

$$\sigma_y(z,t) = [3BAt + \sigma_y^{-3}(z,t=0)]^{-1/3} \qquad \text{(XII-5)}$$

where

$$B = \mu(\frac{1+\nu}{1-\nu}) \ . \qquad \text{(XII-6)}$$

Figure 3 shows a calculation of these stresses done by TSTRESS. Here, we have used the parameters

$$\alpha = 9.5 \times 10^{-6}\ K^{-1}$$

$$\mu = 1.112 \times 10^5 \text{ ksi}$$

$$\nu = 0.33$$

$$h = 5.0 \text{ cm}$$

$$\Delta T = 200 \text{ K} \ .$$

These calculations show excellent agreement between analytic and the numerical TSTRESS results.

To start this calculation on TSTRESS, the input namelist is

```
&BEGIN NMAX=200,
 MSTRXO=0.DO,
```

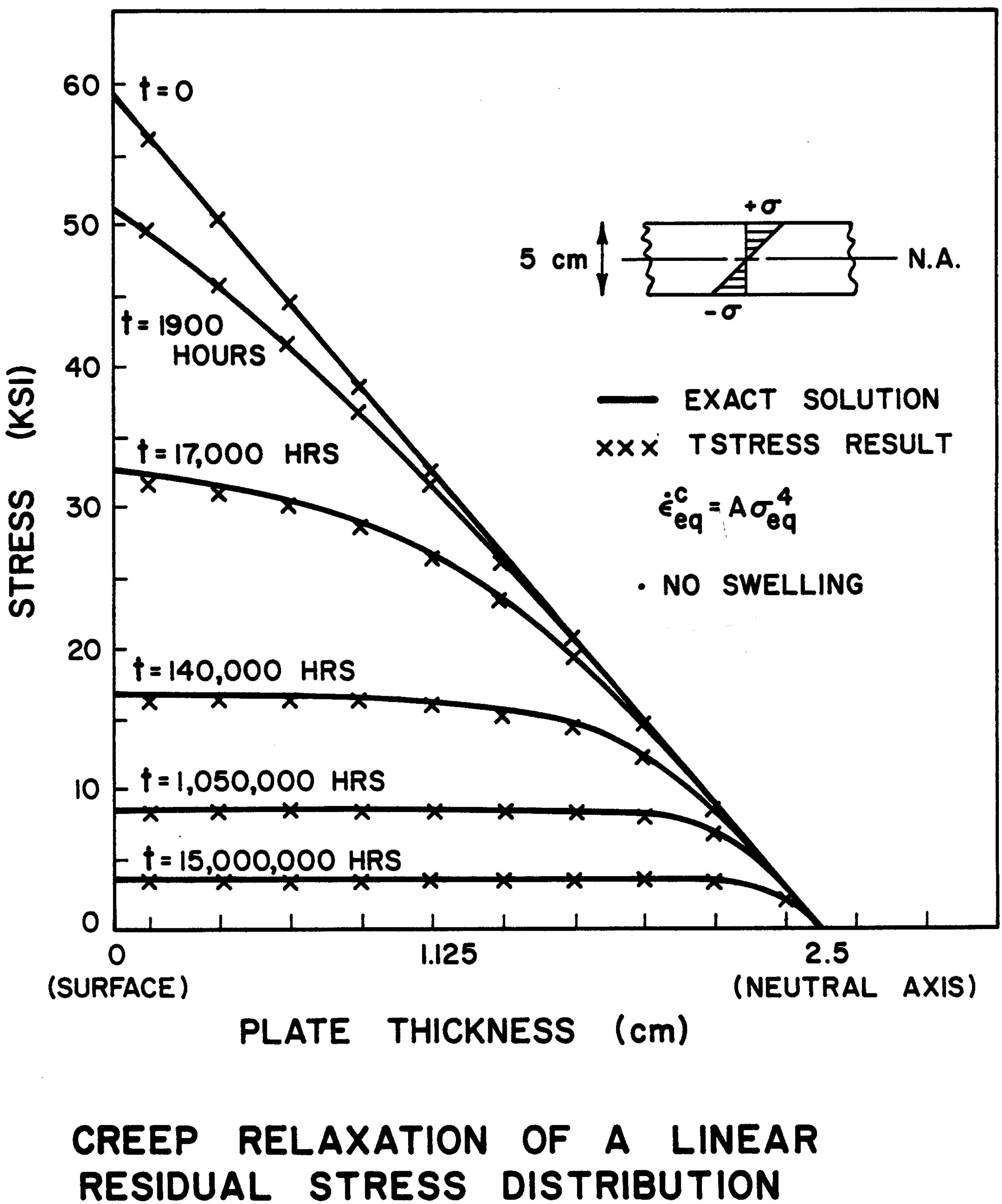


Figure 3 Creep Relaxation of a Linear Residual Stress Distribution.

```
MSTRYO=0.DO,
LINEAR=1,
TFRONT=3.D2,
1ADJ=1,
TBACK=1.D2,
JMAX=20,
DPADOT=0.DO,
TMAX=1.D8,
DTMAX=1.D7,
DZD=20*2.5D-1,
IOUT=3*5,
IRDTMP=1,
NWAIT=1,
NMAX=1,
TTIME=1.DO,
IOBIN=2*100,
TGSIG=5.D-2,
&END .
```

Inertial Confinement Example

A sample of the printed output is presented on the following pages for a run that was started with the input file,

```
&BEGIN NMAX=3000,
    JMAX=32,
    TMAX=4.D-3,
    DTMAX=5.D-5,
```

```
  DPADOT=3.D-7,
  DZD=10*1.D-4,9*1.D-3,13*3.769D-2,18*2.5D-1,
  IOUT=3*1000,
  NEARLY=10,
  NWAIT=1,
  DTEAR=1.D-9,
  TGSIG=.008D0,
  IOBIN=50,20,
&END .
```

This problem is an example of how TSTRESS is currently being used at the University of Wisconsin to calculate the transient stresses in the walls of inertial confinement fusion reactors. The wall temperatures used in this problem come from a temperature diffusion code which calculates the time-dependent temperatures for a given surface heat flux. The output of TSTRESS may be used in a crack growth code to determine the life of the wall.

Acknowledgement

This work was supported by Sandia Laboratories under contract #13-9838.

```
***************************************************
*                                                 *
*    TSTRESS - A CODE TO COMPUTE THE THERMAL      *
*    STRESS IN A PLATE FOR TIME DEPENDENT TEMP    *
*    PROFILES                                     *
*                                                 *
*    WRITTEN BY ROBERT R. PETERSON                *
*                                                 *
***************************************************

              INPUT PARAMETERS

# OF CYCLES ...............     3000
INITIAL CYCLE # ...........        1
# OF ZONES ................       32
STRESS SAVING FREQ ........        1
TIME STEP OUTPUT FREQ .....     1000
ZONE VALUES OUTPUT FREQ ...     1000
GLOBAL VAL OUTPUT FREQ ....     1000
BINARY ZONE OUTPUT FREQ ...       50
BIN HISTORY INCREMENT .....       20
INITIAL TIME ..............   .100000-017
EARLY TIME STEP ...........   .100000-008
# OF EARLY CYCLES .........       10
MAX TIME STEP .............   .500000-004
MAX TIME ..................   .400000-002
MAX # OF CYCLES TO CALC ...        1
DPA RATE ..................   .300000-006
# OF TEMP PROFILES INPUT ..       15
# OF POINTS / INPUT PROF ..       22
INITIAL WIDTH OF PLATE ....   .499970+000
MINIMUM CHANGE RATIO ......   .100000-017
STRESS CHANGE RATIO .......   .800000-002
WIDTH CHANGE RATIO ........   .500000-001
TEMPERATURE CHANGE RATIO ..   .500000-001
X-COMP OF MEM STRESS ......   .0000+000
Y-COMP OF MEM STRESS ......   .0000+000
MANUAL T READ FLAG ........       0
ADJUST MEMBRANE STRESS ....       1
PULSE STRUCTURE TIME ......   .100000-003
TIME STEP EARLY IN PULSE ..   .100000-003

              IVIEW - OPTIONAL OUTPUT PARAMETERS

0      0      0      0      0      0      0      0      0      0
0      0      0      0      0      0      0      0      0      0
0      0      0      0      0      0      0      0      0      0
0      0      0      0      0      0      0      0      0      0
0      0      0      0      0      0      0      0      0      0

              INPUT TEMPERATURE PROFILES

        TZONE(CM) - POSITIONS OF INPUT ZONES

.100000-017   .100000-004   .200000-004   .500000-004   .100000-003
.200000-003   .500000-003   .100000-002   .500000-002   .100000-001
.200000-001   .300000-001   .400000-001   .500000-001   .100000+000
.150000+000   .200000+000   .250000+000   .300000+000   .350000+000
.400000+000   .450000+000   .500000+000

        TTIME(SEC) - TIMES OF INPUT PROFILES

.240000-003   .480000-003   .720000-003   .960000-003   .120000-002
.144000-002   .168000-002   .192000-002   .216000-002   .240000-002
.264000-002   .288000-002   .224000-001   .612000-001   .100000+000
```

TEMP1(DEG K) - INPUT TEMPERATURE PROFILES

| | | | | |
|---|---|---|---|---|
| .578916+003 | .578905+003 | .578876+003 | .578832+003 | .578764+003 |
| .578611+003 | .578300+003 | .577167+003 | .575799+003 | .575285+003 |
| .575183+003 | .575136+003 | .575076+003 | .574921+003 | .574507+003 |
| .573960+003 | .573538+003 | .573273+003 | .573128+003 | .573056+003 |
| .573023+003 | .573009+003 | .573005+003 | | |

| | | | | |
|---|---|---|---|---|
| .582853+003 | .582841+003 | .582808+003 | .582756+003 | .582667+003 |
| .582455+003 | .582005+003 | .580174+003 | .577387+003 | .575704+003 |
| .575218+003 | .575136+003 | .575074+003 | .574919+003 | .574506+003 |
| .573961+003 | .573538+003 | .573273+003 | .573128+003 | .573056+003 |
| .573023+003 | .573009+003 | .573005+003 | | |

| | | | | |
|---|---|---|---|---|
| .584762+003 | .584751+003 | .584722+003 | .584676+003 | .584596+003 |
| .584403+003 | .583986+003 | .582224+003 | .579035+003 | .576401+003 |
| .575325+003 | .575144+003 | .575073+003 | .574918+003 | .574506+003 |
| .573961+003 | .573539+003 | .573274+003 | .573129+003 | .573057+003 |
| .573023+003 | .573009+003 | .573005+003 | | |

| | | | | |
|---|---|---|---|---|
| .585542+003 | .585532+003 | .585508+003 | .585471+003 | .585404+003 |
| .585242+003 | .584891+003 | .583376+003 | .580297+003 | .577147+003 |
| .575507+003 | .575165+003 | .575074+003 | .574917+003 | .574506+003 |
| .573962+003 | .573540+003 | .573275+003 | .573129+003 | .573057+003 |
| .573023+003 | .573009+003 | .573006+003 | | |

| | | | | |
|---|---|---|---|---|
| .585878+003 | .585869+003 | .585848+003 | .585817+003 | .585761+003 |
| .585624+003 | .585326+003 | .584024+003 | .581182+003 | .577818+003 |
| .575742+003 | .575205+003 | .575078+003 | .574916+003 | .574506+003 |
| .573963+003 | .573541+003 | .573275+003 | .573130+003 | .573057+003 |
| .573024+003 | .573009+003 | .573006+003 | | |

| | | | | |
|---|---|---|---|---|
| .586139+003 | .586131+003 | .586112+003 | .586085+003 | .586034+003 |
| .585909+003 | .585639+003 | .584460+003 | .581813+003 | .578391+003 |
| .576006+003 | .575265+003 | .575086+003 | .574916+003 | .574505+003 |
| .573963+003 | .573541+003 | .573276+003 | .573130+003 | .573057+003 |
| .573024+003 | .573010+003 | .573006+003 | | |

| | | | | |
|---|---|---|---|---|
| .587205+003 | .587196+003 | .587174+003 | .587139+003 | .587074+003 |
| .586918+003 | .586588+003 | .585228+003 | .582421+003 | .578899+003 |
| .576282+003 | .575342+003 | .575100+003 | .574918+003 | .574505+003 |
| .573964+003 | .573542+003 | .573276+003 | .573130+003 | .573057+003 |
| .573024+003 | .573010+003 | .573006+003 | | |

| | | | | |
|---|---|---|---|---|
| .588883+003 | .588874+003 | .588852+003 | .588817+003 | .588750+003 |
| .588587+003 | .588231+003 | .586660+003 | .583393+003 | .579461+003 |
| .576568+003 | .575434+003 | .575121+003 | .574920+003 | .574505+003 |
| .573964+003 | .573543+003 | .573277+003 | .573131+003 | .573058+003 |
| .573024+003 | .573010+003 | .573006+003 | | |

| | | | | |
|---|---|---|---|---|
| .588713+003 | .588705+003 | .588687+003 | .588660+003 | .588607+003 |
| .588480+003 | .588200+003 | .586962+003 | .584048+003 | .580044+003 |
| .576873+003 | .575541+003 | .575148+003 | .574925+003 | .574505+003 |
| .573965+003 | .573544+003 | .573277+003 | .573131+003 | .573058+003 |
| .573024+003 | .573010+003 | .573006+003 | | |

| | | | | |
|---|---|---|---|---|
| .588569+003 | .588562+003 | .588546+003 | .588522+003 | .588476+003 |
| .588363+003 | .588117+003 | .587037+003 | .584414+003 | .580524+003 |
| .577184+003 | .575662+003 | .575183+003 | .574931+003 | .574505+003 |
| .573966+003 | .573544+003 | .573278+003 | .573131+003 | .573058+003 |
| .573024+003 | .573010+003 | .573006+003 | | |

| | | | | |
|---|---|---|---|---|
| .588686+003 | .588679+003 | .588664+003 | .588641+003 | .588595+003 |
| .588486+003 | .588247+003 | .587202+003 | .584701+003 | .580919+003 |
| .577489+003 | .575795+003 | .575226+003 | .574940+003 | .574505+003 |
| .573966+003 | .573545+003 | .573279+003 | .573132+003 | .573058+003 |
| .573024+003 | .573010+003 | .573006+003 | | |

| | | | | |
|---|---|---|---|---|
| .589306+003 | .589300+003 | .589284+003 | .589256+003 | .589203+003 |
| .589075+003 | .588801+003 | .587633+003 | .585034+003 | .581277+003 |
| .577783+003 | .575936+003 | .575276+003 | .574952+003 | .574505+003 |
| .573967+003 | .573546+003 | .573279+003 | .573132+003 | .573058+003 |
| .573024+003 | .573010+003 | .573006+003 | | |

| | | | | |
|---|---|---|---|---|
| .578357+003 | .578349+003 | .578332+003 | .578304+003 | .578253+003 |
| .578149+003 | .578001+003 | .577936+003 | .577943+003 | .577885+003 |
| .577701+003 | .577390+003 | .576996+003 | .576089+003 | .574865+003 |
| .574055+003 | .573607+003 | .573326+003 | .573162+003 | .573075+003 |
| .573033+003 | .573014+003 | .573009+003 | | |

| | | | | |
|---|---|---|---|---|
| .576778+003 | .576771+003 | .576754+003 | .576727+003 | .576680+003 |
| .576592+003 | .576490+003 | .576486+003 | .576520+003 | .576500+003 |
| .576446+003 | .576350+003 | .576221+003 | .575897+003 | .575161+003 |
| .574331+003 | .573770+003 | .573427+003 | .573226+003 | .573114+003 |
| .573054+003 | .573025+003 | .573017+003 | | |

| | | | | |
|---|---|---|---|---|
| .576177+003 | .576170+003 | .576153+003 | .576127+003 | .576083+003 |
| .576007+003 | .575933+003 | .575936+003 | .575961+003 | .575951+003 |
| .575923+003 | .575872+003 | .575804+003 | .575625+003 | .575140+003 |
| .574476+003 | .573924+003 | .573541+003 | .573301+003 | .573159+003 |
| .573081+003 | .573041+003 | .573028+003 | | |

| ZONE (#) | TEMP (DEG K) | POISSON'S RATIO | EXP COEF (1/DEG K) | SHEAR MOD (KSI) | CREEP RT (1/KSI-SEC) | SWELL RT (1/SEC) | ZONE WIDTH (CM) | STRESS X (KSI) | STRESS Y (KSI) | POSITION (CM) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .5761+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2341-008 | .1000-003 | -.8700+000 | -.8700+000 | .1000-003 |
| 2 | .5760+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2362-008 | .1000-003 | -.8367+000 | -.8367+000 | .2000-003 |
| 3 | .5760+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2375-008 | .1000-003 | -.8162+000 | -.8162+000 | .3000-003 |
| 4 | .5760+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2382-008 | .1000-003 | -.8062+000 | -.8062+000 | .4000-003 |
| 5 | .5759+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2388-008 | .1000-003 | -.7963+000 | -.7963+000 | .5000-003 |
| 6 | .5759+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2392-008 | .1000-003 | -.7914+000 | -.7914+000 | .6000-003 |
| 7 | .5759+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2391-008 | .1000-003 | -.7917+000 | -.7917+000 | .7000-003 |
| 8 | .5759+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2391-008 | .1000-003 | -.7919+000 | -.7919+000 | .8000-003 |
| 9 | .5759+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2391-008 | .1000-003 | -.7921+000 | -.7921+000 | .9000-003 |
| 10 | .5759+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2391-008 | .1000-003 | -.7924+000 | -.7924+000 | .1000-002 |
| 11 | .5759+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2390-008 | .1000-002 | -.7938+000 | -.7938+000 | .2000-002 |
| 12 | .5759+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2368-008 | .1000-002 | -.7963+000 | -.7963+000 | .3000-002 |
| 13 | .5760+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2387-008 | .1000-002 | -.7988+000 | -.7988+000 | .4000-002 |
| 14 | .5760+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2385-008 | .1000-002 | -.8013+000 | -.8013+000 | .5000-002 |
| 15 | .5760+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2385-008 | .1000-002 | -.8021+000 | -.8021+000 | .6000-002 |
| 16 | .5760+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2385-008 | .1000-002 | -.8013+000 | -.8013+000 | .7000-002 |
| 17 | .5760+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2386-008 | .1000-002 | -.8004+000 | -.8004+000 | .8000-002 |
| 18 | .5760+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2386-008 | .1000-002 | -.7996+000 | -.7996+000 | .9000-002 |
| 19 | .5760+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2387-008 | .1000-002 | -.7987+000 | -.7987+000 | .1000-001 |
| 20 | .5759+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2406-008 | .3769-001 | -.7688+000 | -.7688+000 | .4769-001 |
| 21 | .5755+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2516-008 | .3769-001 | -.6008+000 | -.6008+000 | .8538-001 |
| 22 | .5751+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2617-008 | .3769-001 | -.4459+000 | -.4459+000 | .1231+000 |
| 23 | .5746+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2750-008 | .3769-001 | -.2424+000 | -.2424+000 | .1608+000 |
| 24 | .5741+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2866-008 | .3769-001 | -.6605-001 | -.6605-001 | .1984+000 |
| 25 | .5738+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2962-008 | .3769-001 | .7921-001 | .7921-001 | .2361+000 |
| 26 | .5735+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3036-008 | .3769-001 | .1908+000 | .1908+000 | .2738+000 |
| 27 | .5733+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3085-008 | .3769-001 | .2646+000 | .2646+000 | .3115+000 |
| 28 | .5732+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3118-008 | .3769-001 | .3138+000 | .3138+000 | .3492+000 |
| 29 | .5731+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3140-008 | .3769-001 | .3478+000 | .3478+000 | .3869+000 |
| 30 | .5731+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3155-008 | .3769-001 | .3700+000 | .3700+000 | .4246+000 |
| 31 | .5730+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3163-008 | .3769-001 | .3623+000 | .3823+000 | .4623+000 |
| 32 | .5730+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3167-008 | .3769-001 | .3878+000 | .3876+000 | .5000+000 |

| CYCLE | TIME(SEC) | TIME STEP(SEC) | LIMITING CONDITION(SIGY) | WOULD BE(SIGY) IN ZONE( 20) |
|---|---|---|---|---|
| 1000 | .195633-003 | .355365-006 | | |

| ZONE (#) | TEMP (DEG K) | POISSON'S RATIO | EXP COEF (1/DEG K) | SHEAR MOD (KSI) | CREEP RT (1/KSI-SEC) | SWELL RT (1/SEC) | ZONE WIDTH (CM) | STRESS X (KSI) | STRESS Y (KSI) | POSITION (CM) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .5783+C03 | .2950+000 | .1220-004 | .9070+004 | .1266-011 | .1764-008 | .1001-003 | -.1589+001 | -.1589+001 | .1001-003 |
| 2 | .5782+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .1798-008 | .1001-003 | -.1543+001 | -.1543+001 | .2002-003 |
| 3 | .5781+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .1828-008 | .1001-003 | -.1510+001 | -.1510+001 | .3004-003 |
| 4 | .5780+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .1851-008 | .1001-003 | -.1490+001 | -.1490+001 | .4005-003 |
| 5 | .5779+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .1874-008 | .1001-003 | -.1469+001 | -.1469+001 | .5006-003 |
| 6 | .5778+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .1910-008 | .1001-003 | -.1447+001 | -.1447+001 | .6007-003 |
| 7 | .5776+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .1958-008 | .1001-003 | -.1422+001 | -.1422+001 | .7008-003 |
| 8 | .5774+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2007-008 | .1001-003 | -.1397+001 | -.1397+001 | .8009-003 |
| 9 | .5772+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2055-008 | .1001-003 | -.1372+001 | -.1372+001 | .9011-003 |
| 10 | .5770+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2103-008 | .1001-003 | -.1348+001 | -.1348+001 | .1001-002 |
| 11 | .5768+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2163-008 | .1001-002 | -.1313+001 | -.1313+001 | .2002-002 |
| 12 | .5765+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2236-008 | .1001-002 | -.1267+001 | -.1267+001 | .3004-002 |
| 13 | .5762+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2310-008 | .1001-002 | -.1222+001 | -.1222+001 | .4005-002 |
| 14 | .5760+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2383-008 | .1001-002 | -.1177+001 | -.1177+001 | .5006-002 |
| 15 | .5758+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2430-008 | .1001-002 | -.1142+001 | -.1142+001 | .6007-002 |
| 16 | .5757+C03 | .2950+000 | .1220-004 | .9070+C04 | .1265-011 | .2453-008 | .1001-002 | -.1118+001 | -.1118+001 | .7008-002 |
| 17 | .5756+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2475-008 | .1001-002 | -.1094+001 | -.1094+001 | .8009-002 |
| 18 | .5755+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2498-008 | .1001-002 | -.1070+001 | -.1070+001 | .9011-002 |
| 19 | .5754+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2520-008 | .1001-002 | -.1046+001 | -.1046+001 | .1001-001 |
| 20 | .5753+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2565-008 | .3773-001 | -.9593+C00 | -.9593+000 | .4775-001 |
| 21 | .5749+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2663-008 | .3773-001 | -.7580+000 | -.7580+000 | .8548-001 |
| 22 | .5746+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2753-008 | .3773-001 | -.5723+000 | -.5723+000 | .1232+000 |
| 23 | .5741+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2867-008 | .3773-001 | -.3320+000 | -.3320+000 | .1609+000 |
| 24 | .5738+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2963-008 | .3773-001 | -.1237+000 | -.1237+000 | .1987+000 |
| 25 | .5735+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3039-008 | .3773-001 | .4849-001 | .4849-001 | .2364+000 |
| 26 | .5733+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3093-008 | .3773-001 | .1819+000 | .1819+000 | .2741+000 |
| 27 | .5732+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3126-008 | .3773-001 | .2722+000 | .2722+000 | .3119+000 |
| 28 | .5731+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3147-008 | .3773-001 | .3349+000 | .3349+000 | .3496+000 |
| 29 | .5731+C03 | .2950+000 | .1220-004 | .9070+C04 | .1265-011 | .3160-008 | .3773-001 | .3809+000 | .3809+000 | .3874+000 |
| 30 | .5730+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3167-008 | .3773-001 | .4138+000 | .4138+000 | .4251+000 |
| 31 | .5730+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3171-008 | .3773-001 | .4360+000 | .4360+000 | .4628+000 |
| 32 | .5730+C03 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3173-008 | .3773-001 | .4509+000 | .4509+000 | .5006+000 |

GLOBAL QUANTITIES

| | | | |
|---|---|---|---|
| MAXIMUM X - COMP OF TOTAL STRESS | = -.158931+001 | IN ZONE # | 1 |
| MAXIMUM Y - COMP OF TOTAL STRESS | = -.158931+001 | IN ZONE # | 1 |
| FASTEST TEMP CHANGE | = .989647+006 | IN ZONE # | 1 |
| THICKNESS OF PLATE | = .500552+000 | | |

MEMBRANE STRESS CONSERVATION (KSI)

| | THIS CYCLE | ORIGINALLY |
|---|---|---|
| X-COMPONENT | -.2045-001 | .0000+000 |
| Y-COMPONENT | -.2045-001 | .0000+000 |

| CYCLE | TIME(SEC) | TIME STEP(SEC) | LIMITING CONDITION(SIGY) | WOULD BE(SIGY) IN ZONE( 20) |
|---|---|---|---|---|
| 1432 | .399361-002 | .500000-004 | | |

| ZONE (#) | TEMP (DEG K) | POISSON'S RATIO | EXP COEF (1/DEG K) | SHEAR MOD (KSI) | CREEP RT (1/KSI-SEC) | SWELL RT (1/SEC) | ZONE WIDTH (CM) | STRESS X (KSI) | STRESS Y (KSI) | POSITION (CM) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .5886+003 | .2950+000 | .1220-004 | .9070+004 | .1268-011 | -.7949-009 | .1002-003 | -.5365+001 | -.5365+001 | .1002-003 |
| 2 | .5885+003 | .2950+000 | .1220-004 | .9070+004 | .1268-011 | -.7672-009 | .1002-003 | -.5326+001 | -.5326+001 | .2004-003 |
| 3 | .5884+003 | .2950+000 | .1220-004 | .9070+004 | .1268-011 | -.7415-009 | .1002-003 | -.5295+001 | -.5295+001 | .3006-003 |
| 4 | .5883+003 | .2950+000 | .1220-004 | .9070+004 | .1268-011 | -.7202-009 | .1002-003 | -.5275+001 | -.5275+001 | .4008-003 |
| 5 | .5882+003 | .2950+000 | .1220-004 | .9070+004 | .1268-011 | -.6990-009 | .1002-003 | -.5254+001 | -.5254+001 | .5009-003 |
| 6 | .5881+003 | .2950+000 | .1220-004 | .9070+004 | .1268-011 | -.6616-009 | .1002-003 | -.5224+001 | -.5224+001 | .6011-003 |
| 7 | .5879+003 | .2950+000 | .1220-004 | .9070+004 | .1268-011 | -.6087-009 | .1002-003 | -.5185+001 | -.5185+001 | .7013-003 |
| 8 | .5876+003 | .2950+000 | .1220-004 | .9070+004 | .1268-011 | -.5557-009 | .1002-003 | -.5146+001 | -.5146+001 | .8015-003 |
| 9 | .5874+003 | .2950+000 | .1220-004 | .9070+004 | .1268-011 | -.5025-009 | .1002-003 | -.5107+001 | -.5107+001 | .9017-003 |
| 10 | .5872+003 | .2950+000 | .1220-004 | .9070+004 | .1268-011 | -.4493-009 | .1002-003 | -.5068+001 | -.5068+001 | .1002-002 |
| 11 | .5868+003 | .2950+000 | .1220-004 | .9070+004 | .1267-011 | -.3493-009 | .1002-002 | -.4963+001 | -.4963+001 | .2004-002 |
| 12 | .5862+003 | .2950+000 | .1220-004 | .9070+004 | .1267-011 | -.2007-009 | .1002-002 | -.4791+001 | -.4791+001 | .3006-002 |
| 13 | .5855+003 | .2950+000 | .1220-004 | .9070+004 | .1267-011 | -.5122-010 | .1002-002 | -.4618+001 | -.4618+001 | .4007-002 |
| 14 | .5849+003 | .2950+000 | .1220-004 | .9070+004 | .1267-011 | .9901-010 | .1002-002 | -.4446+001 | -.4446+001 | .5009-002 |
| 15 | .5843+003 | .2950+000 | .1220-004 | .9070+004 | .1267-011 | .2622-009 | .1002-002 | -.4226+001 | -.4226+001 | .6011-002 |
| 16 | .5836+003 | .2950+000 | .1220-004 | .9070+004 | .1267-011 | .4381-009 | .1002-002 | -.3959+001 | -.3959+001 | .7013-002 |
| 17 | .5828+003 | .2950+000 | .1220-004 | .9070+004 | .1266-011 | .6150-009 | .1002-002 | -.3692+001 | -.3692+001 | .8015-002 |
| 18 | .5821+003 | .2950+000 | .1220-004 | .9070+004 | .1266-011 | .7930-009 | .1002-002 | -.3425+001 | -.3425+001 | .9017-002 |
| 19 | .5814+003 | .2950+000 | .1220-004 | .9070+004 | .1266-011 | .9720-009 | .1002-002 | -.3159+001 | -.3159+001 | .1002-001 |
| 20 | .5762+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2318-008 | .3776-001 | -.1121+001 | -.1121+001 | .4777-001 |
| 21 | .5749+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2678-008 | .3776-001 | -.5491+000 | -.5491+000 | .8553-001 |
| 22 | .5745+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2779-008 | .3776-001 | -.3492+000 | -.3492+000 | .1233+000 |
| 23 | .5741+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2891-008 | .3776-001 | -.1130+000 | -.1130+000 | .1610+000 |
| 24 | .5737+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .2982-008 | .3776-001 | .8582-001 | .8582-001 | .1968+000 |
| 25 | .5735+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3053-008 | .3776-001 | .2461+000 | .2461+000 | .2366+000 |
| 26 | .5733+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3104-008 | .3776-001 | .3661+000 | .3661+000 | .2743+000 |
| 27 | .5732+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3134-008 | .3776-001 | .4419+000 | .4419+000 | .3121+000 |
| 28 | .5731+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3152-008 | .3776-001 | .4901+000 | .4901+000 | .3498+000 |
| 29 | .5730+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3163-008 | .3776-001 | .5217+000 | .5217+000 | .3876+000 |
| 30 | .5730+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3170-008 | .3776-001 | .5407+000 | .5407+000 | .4253+000 |
| 31 | .5730+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3173-008 | .3776-001 | .5496+000 | .5496+000 | .4631+000 |
| 32 | .5730+003 | .2950+000 | .1220-004 | .9070+004 | .1265-011 | .3174-008 | .3776-001 | .5519+000 | .5519+000 | .5008+000 |

MAXIMUM X-COMP OF TOTAL STRESS = -.5613+001 KSI IN ZONE # 1 AT TIME .2794-002 SEC

MAXIMUM Y-COMP OF TOTAL STRESS = -.5613+001 KSI IN ZONE # 1 AT TIME .2794-002 SEC

TOTAL STRESS(KSI) IN ZONE 1

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| -.8700+000 | -.8757+000 | -.8827+000 | -.8899+000 | -.8970+000 | -.9043+000 | -.9116+000 | -.9189+000 | -.9263+000 | -.9338+000 |
| -.9413+000 | -.9489+000 | -.9565+000 | -.9642+000 | -.9720+000 | -.9798+000 | -.9877+000 | -.9956+000 | -.1004+001 | -.1012+001 |
| -.1020+001 | -.1029+001 | -.1037+001 | -.1046+001 | -.1054+001 | -.1063+001 | -.1072+001 | -.1082+001 | -.1091+001 | -.1101+001 |
| -.1111+001 | -.1122+001 | -.1134+001 | -.1147+001 | -.1161+001 | -.1176+001 | -.1192+001 | -.1210+001 | -.1229+001 | -.1249+001 |
| -.1272+001 | -.1295+001 | -.1321+001 | -.1349+001 | -.1379+001 | -.1412+001 | -.1447+001 | -.1492+001 | -.1540+001 | -.1589+001 |
| -.1641+001 | -.1695+001 | -.1751+001 | -.1819+001 | -.1891+001 | -.1731+001 | -.1827+001 | -.2070+001 | -.2283+001 | -.2536+001 |
| -.2949+001 | -.3391+001 | -.3800+001 | -.4118+001 | -.4337+001 | -.4539+001 | -.5009+001 | -.5468+001 | -.5528+001 | -.5506+001 |
| -.5491+001 | | | | | | | | | |

TIME(SEC)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| .1223-006 | .6616-005 | .1339-004 | .1944-004 | .2492-004 | .2996-004 | .3464-004 | .3902-004 | .4316-004 | .4709-004 |
| .5083-004 | .5442-004 | .5787-004 | .6121-004 | .6443-004 | .6756-004 | .7060-004 | .7356-004 | .7647-004 | .7934-004 |
| .8215-004 | .8491-004 | .8762-004 | .9032-004 | .9297-004 | .9559-004 | .9820-004 | .1008-003 | .1034-003 | .1061-003 |
| .1088-003 | .1116-003 | .1145-003 | .1176-003 | .1209-003 | .1243-003 | .1280-003 | .1317-003 | .1357-003 | .1399-003 |
| .1442-003 | .1487-003 | .1534-003 | .1583-003 | .1636-003 | .1690-003 | .1747-003 | .1815-003 | .1885-003 | .1956-003 |
| .2028-003 | .2099-003 | .2172-003 | .2255-003 | .2341-003 | .2402-003 | .2566-003 | .2993-003 | .3378-003 | .3851-003 |
| .4660-003 | .5648-003 | .6917-003 | .8554-003 | .1077-002 | .1377-002 | .1677-002 | .1954-002 | .2194-002 | .2473-002 |
| .3394-002 | | | | | | | | | |

PLATE WIDTH(CM)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| .5000+000 | .5000+000 | .5000+000 | .5000+000 | .5000+000 | .5000+000 | .5000+000 | .5000+000 | .5000+000 | .5000+000 |
| .5000+000 | .5000+000 | .5000+000 | .5000+000 | .5000+000 | .5000+000 | .5000+000 | .5001+000 | .5001+000 | .5001+000 |
| .5001+000 | .5001+000 | .5001+000 | .5001+000 | .5001+000 | .5001+000 | .5001+000 | .5001+000 | .5001+000 | .5001+000 |
| .5002+000 | .5002+000 | .5002+000 | .5002+000 | .5002+000 | .5002+000 | .5002+000 | .5002+000 | .5003+000 | .5003+000 |
| .5003+000 | .5003+000 | .5003+000 | .5004+000 | .5004+000 | .5004+000 | .5004+000 | .5005+000 | .5005+000 | .5006+000 |
| .5006+000 | .5006+000 | .5007+000 | .5007+000 | .5008+000 | .5008+000 | .5008+000 | .5008+000 | .5008+000 | .5008+000 |
| .5008+000 | .5008+000 | .5008+000 | .5008+000 | .5008+000 | .5008+000 | .5008+000 | .5008+000 | .5008+000 | .5008+000 |
| .5008+000 | | | | | | | | | |