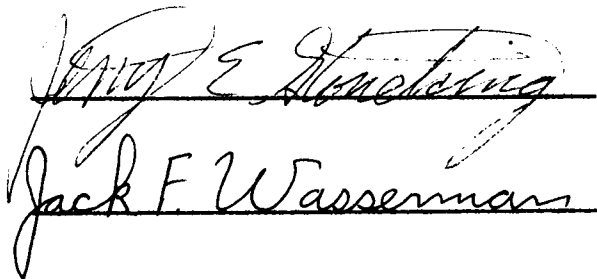


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**COMPUTER AUTOMATION PROCESS FOR THE DESIGN OF
SINGLE AND MULTIPLE WALLED HIGH PRESSURE
VESSELS**

**A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville**

**Richard Blaine Sparks
August 1992**

ACKNOWLEDGEMENTS

I would like to extend my thanks to my major professor, Dr. Jerry Carley, for his consideration, patience and for guiding me in this project. I would also like to thank Dr. Jack Wasserman and Dr. J.E. Stoneking for their time and effort in reviewing and evaluating this thesis. I would like to thank the department of Engineering Science and Mechanics, for providing me with a teaching assistantship, which allowed me to pursue my masters degree. I would like to thank Eunice Hinkle for all of her support throughout my undergraduate and graduate work. Finally I would like to thank my parents, Richard and Nancy Sparks, and my wife Lois for their support during this project.

ABSTRACT

The purpose of this thesis was to develop a user friendly software package to speed the calculation of the stress states of high pressure multiple walled vessels. A residual stress pattern is created in these vessels using autofrettage and the shrinkfitting processes. This residual stress pattern improves the vessel's ability to perform at high pressures. The solution method considers the effects of strain hardening and the Bauschinger effect. The software was implemented to perform on a Macintosh platform. The Macintosh was chosen for the software development because, in the author's opinion, Macintosh's intuitive user interface will allow the widest use of the software. This software package allows the criteria of the problem to be quickly changed so that the user may produce a design for a high pressure vessel in an efficient manner. The software also generates stress graphs, and a complete report for each design providing the user with complete documentation of the design generated.

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Chapter I

Introduction And Purpose

Autofrettage and shrink fit processes are used to produce a residual stress distribution in thick walled cylindrical pressure vessels. In the autofrettage process a large internal pressure is applied to the vessel. This pressure causes plastic deformation in part or all of the cylinder. When the pressure is released, a residual stress state remains in the cylinder. In the shrinkfitting process, two cylinders are assembled together to form a multi-layered vessel. The larger of the cylinders has an inside diameter that is slightly smaller than the outside diameter of the smaller cylinder. When assembled the interference fit causes an interface pressure between the cylinders which produces a beneficial residual stress state in the vessel. These methods may be used alone or in combination. The desired residual stress state, which consists of residual compressive circumferential stresses at the bore of the vessel, allows a greater operating pressure to be used in these vessels. This residual stress state has the following beneficial effects:.

1. The pressure at which yielding will occur in the cylinder is increased.
2. The fatigue life is increased due to the reduction of the effective cyclic bore stresses.

In order to design a vessel, which for the above reasons has a residual stress pattern caused by autofrettage or a shrink fit, the stresses for a given configuration must

be calculated and modified until an acceptable configuration is found. Since these calculations are long and tedious, automation of the stress calculations will greatly reduce the amount of time required to design such a vessel.

Chapter II

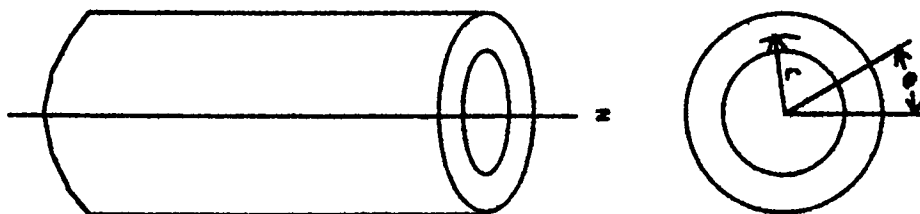
Mathematical Basis Of The Stress Analysis Procedure

Autofrettage of Thick Walled Cylinders

One method of achieving the desired residual stress pattern in a pressure vessel is by using an autofrettage process. The autofrettage process involves pressurizing the vessel internally until yielding occurs in some or all of the material. When the autofrettage pressure is released, a residual stress pattern remains in the material. Cylindrical pressure vessels will be considered here.

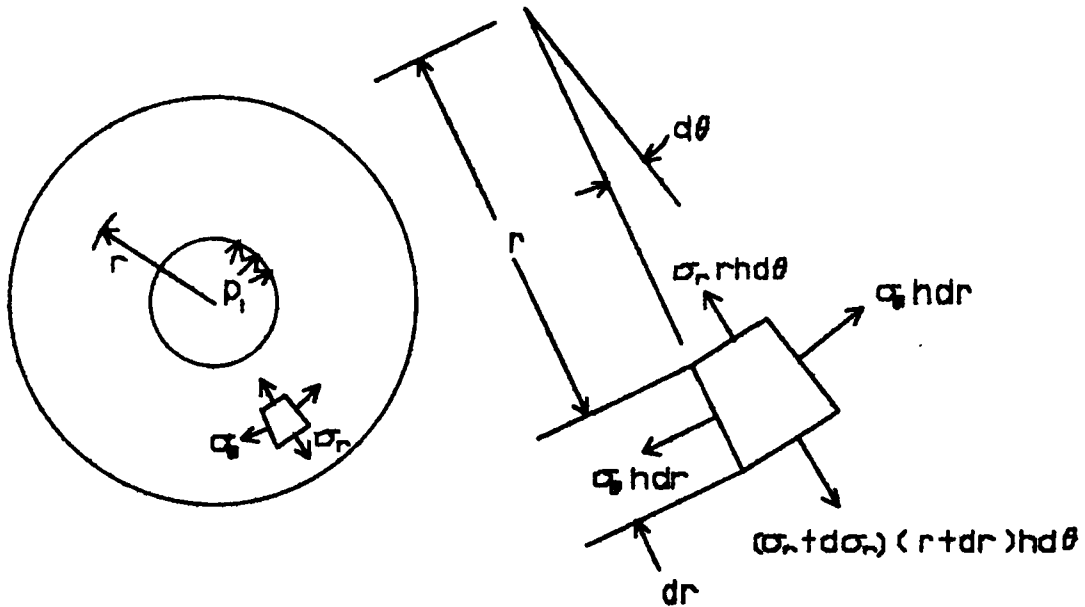
As a cylinder is pressurized beyond a certain level, the material begins to yield, starting at the bore and continuing outward as the pressure is increased. In order to determine the depth of the yielded zone, some theory of failure must be selected. Two theories of failure will be considered for the calculation of the stress state in the yielded zone, the Tresca theory and the Von Mises theory.

The Tresca theory states that a material will begin to yield when the maximum shear stress reaches some limiting value. The von Mises theory states that the material will begin to yield when the octahedral shear stress reaches some limiting value. Using Mohr's Circle, and assuming that the axial stress is equal to zero in the polar coordinate system defined below, it may be shown that when yielding occurs, the principal stress difference is given by (1).



$$\sigma_{\theta} - \sigma_r = k\tau \quad (1)$$

For the Tresca theory $k=2$, τ =maximum shear stress. For the von Mises theory $k=3/\sqrt{2}$, and τ =octahedral shear stress.



where:

h = typical length along the cylinder.

p_i = internal pressure.

The above drawing shows a differential element taken from the vessel wall. From equilibrium of the above radial force components it is seen that

$$\frac{d\sigma_r}{dr} + \frac{\sigma_r - \sigma_{\theta}}{r} = 0 \quad (2)$$

Substituting(1) into(2) yields (3).

$$\frac{d\sigma_r}{dr} = \frac{k\tau}{r} \quad (3)$$

Integrating (3) yields the following expression for variation of the radial stress in the yielded zone of the cylinder.

$$\sigma_r = k\tau \ln(r) + c \quad (4)$$

At the bore, $r = r_i$ and $\sigma_r = -p$ (where p = autofrettage pressure). Using these conditions and solving for c yields (5).

$$c = -p - k\tau \ln(r_i) \quad (5)$$

Substituting (5) into (4) yields (6), the expression for the radial stress as a function of r in the yielded zone of the cylinder.

$$\sigma_r = k\tau \ln\left(\frac{r}{r_i}\right) - p \quad (6)$$

Putting this result back into (1) gives an expression for the circumferential stress in the yielded zone of the cylinder.

$$\sigma_\theta = \sigma_r + k\tau \quad (7)$$

The equations (6) and (7) are valid for the region of the material which has undergone plastic deformation.

Since in most cases the plastic deformation does not proceed throughout the entire thickness of the cylinder, it is necessary to determine the stress state in the region where the material does not yield. If u represents the radial displacement of a point, and since displacements occur strictly in a radial direction for axisymmetric problems, the circumferential strain may be written as the change in circumference divided by the original circumference.

$$\epsilon_{\theta} = \frac{2\pi (r + u) - 2\pi r}{2\pi r}$$

or

$$\epsilon_{\theta} = \frac{u}{r} \quad (8)$$

The radial strain of a differential line segment dr , that changes its length by an amount du , may be written as follows. (See drawing on page

$$\epsilon_r = \frac{du}{dr} \quad (9)$$

The stress-strain relationships for a planar state of stress with uniform temperature for an isotropic, homogeneous material are:

$$\sigma_r = \frac{E}{1 - \nu^2} [\epsilon_r + \nu \epsilon_{\theta}] \quad (10)$$

$$\sigma_{\theta} = \frac{E}{1-\nu^2} \{\epsilon_{\theta} + \nu \epsilon_r\} \quad (11)$$

Substituting (8) and (9) into (11) yields the following expressions for radial and circumferential stresses in the unyielded zone of the cylinder.

$$\sigma_r = \frac{E}{1-\nu^2} \{\epsilon_r + \nu \epsilon_{\theta}\} = \frac{E}{1-\nu^2} \left\{ \frac{du}{dr} + \nu \frac{u}{r} \right\} \quad (12)$$

$$\sigma_{\theta} = \frac{E}{1-\nu^2} \{\epsilon_{\theta} + \nu \epsilon_r\} = \frac{E}{1-\nu^2} \left\{ \frac{u}{r} + \nu \frac{du}{dr} \right\} \quad (13)$$

Substituting (12) and (13) into (2) yields the following differential equation for the radial displacement.

$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} - \frac{u}{r^2} = 0 \quad (14)$$

Rewriting (14) yields the following expression.

$$\frac{d}{dr} \left[\frac{1}{r} \frac{d}{dr} (ur) \right] = 0 \quad (15)$$

By integrating (15) twice the following solution is obtained:

$$u = C_1 r + \frac{C_2}{r} \quad (16)$$

Substituting (16) into (12) and (13) yields the following expressions for the stresses in the unyielded part of the cylinder.

$$\sigma_r = \frac{E}{1-\nu^2} \left[(1+\nu) C_1 - \frac{1-\nu}{r^2} C_2 \right] \quad (17)$$

$$\sigma_\theta = \frac{E}{1-\nu^2} \left[(1+\nu) C_1 + \frac{1-\nu}{r^2} C_2 \right] \quad (18)$$

At the inner surface the magnitude of the radial stress must be equal to the internal pressure.

$$\text{At } r = r_i, \sigma_r = -p_i. \quad (19a)$$

At the outer surface of the cylinder the radial stress must be equal to the external pressure.

$$\text{At } r = r_o, \sigma_r = -p_o. \quad (19b)$$

When these boundary conditions are applied to (17) and (18), the following results are obtained for the constants of integration in (17) and (18).

$$C_1 = \frac{1-\nu}{E} \left[\frac{r_i^2 p_i - r_o^2 p_o}{r_o^2 - r_i^2} \right] \quad (20a)$$

$$C_2 = \frac{1+\nu}{E} \left[\frac{r_i^2 r_o^2 (p_i - p_o)}{r_o^2 - r_i^2} \right] \quad (20b)$$

Substituting C_1 and C_2 into (17) and (18) the following equations for the stress state in the elastic region of the cylinder are found.

$$\sigma_r = \frac{p_i r_i^2}{r_o^2 - r_i^2} \left(1 - \frac{r_o^2}{r^2} \right) - \frac{p_o r_o^2}{r_o^2 - r_i^2} \left(1 - \frac{r_i^2}{r^2} \right) \quad (21)$$

$$\sigma_\theta = \frac{p_i r_i^2}{r_o^2 - r_i^2} \left(1 + \frac{r_o^2}{r^2} \right) - \frac{p_o r_o^2}{r_o^2 - r_i^2} \left(1 + \frac{r_i^2}{r^2} \right) \quad (22)$$

In order to determine which regions of the cylinder that the equations describing the radial and circumferential stresses should be applied, it is necessary to calculate the depth through which yielding occurs. If the depth of yielding is a given parameter, then the pressure required to cause this depth of yielding must be calculated. The interface pressure that exists between the elastic and plastic zones must also be found. This plastic-elastic interface pressure may be found by substituting (21) and (22) into the yield condition given in (1). This substitution yields the following expression for the interface pressure.

$$p_c = k\tau \frac{r_o^2 - r_p^2}{2r_o^2} \quad (23)$$

Where r_p = depth of yielding.

There are two cases that must be examined in solving autofrettage problems.

1. The depth of the plastic action is known and the autofrettage pressure must be found.

The autofrettage pressure may be found by using (6).

$$\sigma_r = k\tau \ln \left(\frac{r}{r_i} \right) - p \quad (6)$$

Where σ_r is equal to the interface pressure between the plastic and elastic zones and r is set equal to the depth of yielding. The interface pressure is given by (23). Substituting (23) for σ_r and r_p for r into (6) yields.

$$p_{auto} = k\tau \left\{ \left(\ln \frac{r_p}{r_i} \right) + \left(\frac{r_o^2 - r_p^2}{2r_o^2} \right) \right\} \quad (24)$$

2. In the second case the autofrettage pressure is known and the depth of yielding must be found. For this case the following form of (24) must be solved by a root finding procedure. The root finding procedure will determine the value of r_p by substituting various values of r_p into (25) until a value that causes (25) to be equal to zero is found. The bisection method is used for this calculation. For an outline of the bisection method see appendix A.

$$f(r_p) = k\tau \left[\left(\ln \frac{r_p}{r_i} \right) + \left(\frac{r_o^2 - r_p^2}{2r_o^2} \right) \right] - p_{auto} = 0 \quad (25)$$

The designer must also know the pressure at which yielding will begin, and the pressure at which yielding will proceed completely through the cylinder. When yielding

begins, $r_p=r_i$ and the interface pressure is equal to the autofrettage pressure. Substituting r_i for r_p and the autofrettage pressure for the interface pressure into (23) yields an expression for the pressure at which yielding begins.

$$\text{Pressure at which yielding begins} = k\tau \left(\frac{r_o^2 - r_i^2}{2r_o^2} \right) \quad (26)$$

When yielding is complete $r_p=r_o$ and $\sigma_r=0$ at r_o . Substituting these values into the equation that describes the stress state in the plastic region of the cylinder, (6), yields the following expression.

$$\text{Pressure at which yielding is complete} = k\tau \left\{ \ln \frac{r_o}{r_i} \right\} \quad (27)$$

Using the equations given thus far, it is possible to calculate the stresses in the cylinder that are caused by the autofrettage pressure. The next step is to calculate the residual stresses that are left after the autofrettage pressure is released. These stresses may be found by superimposing the stresses caused by the application of the autofrettage pressure, and the stresses caused during the unloading of the autofrettage pressure. The unloading stresses may be calculated by using the elastic equations, (21) and (22), and replacing the internal pressure with the negative of the autofrettage pressure. It is necessary to check and see if the cylinder re-yields during the release of the autofrettage pressure. It has been shown experimentally, Kendall(1), that the re-yielding pressure is significantly less than that predicted from the Tresca yield condition and elastic unloading. Thus when re-yielding occurs, a correction for the Bauschinger effect will be used to more properly

estimate the stress state of the vessel. This will be explained in detail in a later section of this thesis.

Shrinkfit of Thick Walled Cylinders

Another method to produce the desired residual stress at the bore of the cylinder is to shrinkfit a second cylinder onto the original cylinder. The larger of the two cylinders will have a slightly smaller inner radius than the outer radius of the smaller cylinder. These cylinders are assembled by heating the larger cylinder until it will fit over the smaller cylinder, assembling them and allowing the outer cylinder to cool. This will produce a contact pressure between the two cylinders, and the desired type of stress pattern (compressive circumferential stress at the bore of the inner cylinder). Since it is possible for the cylinders to have different material properties, the problem must be solved for the case which occurs when the moduli of elasticity of the cylinders are different. For elastic plane stress (See Figure 1), in an isotropic material:

$$\epsilon_{\theta} = \frac{1}{E}(\sigma_{\theta} - \nu \sigma_r) \quad (28)$$

and

$$\epsilon_{\theta} = \frac{u}{r} \quad (29)$$

Where u is the radial displacement of a point at some radius r .

From (29) the change in radius at the outer surface of the inner cylinder is equal to the following.

$$u_i = r_o \epsilon_\theta \quad (30)$$

Where r_o = the outer radius of the inner cylinder.

Using the elastic equations for stress, (21) and (22), and substituting these into (30) yields the equation giving the change in radius of the inner cylinder.

$$u_i = \frac{r_o}{E_i} \left[\left(-\frac{p_{int} r_o^2}{r_o^2 - r_i^2} \right) \left(1 + \frac{r_i^2}{r_o^2} \right) + v_i p_{int} \right] \quad (31)$$

similarly, the change in the inner radius of the outer cylinder is expressed by the following

$$u_o = R_o \epsilon_\theta \quad (32)$$

$$u_o = \frac{r_o}{E_o} \left[\left(\frac{p_{int} r_o^2}{R_o^2 - R_i^2} \right) \left(1 + \frac{R_o^2}{r_o^2} \right) + v_o p_{int} \right] \quad (33)$$

Where:

r_i = the inner radius of the inner cylinder.

r_o = the outer radius of the inner cylinder.

R_i = the inner radius of the outer cylinder.

R_o = the outer radius of the outer cylinder.

v_i = Poisson's ratio in the inner cylinder.

v_o = Poisson's ratio in the outer cylinder.

E_i = The modulus of elasticity of the inner cylinder.

E_o = The modulus of elasticity of the outer cylinder.

The known shrink fit, Δ , is equal to $R_i - r_o = u_o - u_i$.
Substituting u_o (change in inner radius of the outer cylinder) and u_i (change in outer radius of the inner

cylinder) into (33) and solving for the interface pressure yields the following expression for the interface pressure.

$$p_{int} = \Delta \left\{ \frac{r_o}{E_o} \left[\left(\frac{r_o^2}{R_o^2 - R_i^2} \right) \left(1 + \frac{R_o^2}{r_o^2} \right) + \nu_o \right] + \frac{r_o}{E_i} \left[\left(-\frac{r_o^2}{r_o^2 - r_i^2} \right) \left(1 + \frac{r_i^2}{r_o^2} \right) - \nu_i \right] \right\}^{-1}$$

(34)

The stress state caused by the shrink fitting process may be found by using the interface pressure and the elastic equations (21) and (22). The interface pressure is considered to be an external pressure on the inner cylinder, and a internal pressure on the external cylinder. If the autofrettage process has previously been performed on the inner cylinder, the stresses caused by the shrink fit are superimposed on the residual stresses caused by the autofrettage process.

Bauschinger Effect

According to a study done by Kendall(1), the pressure at which a thick cylinder will reyield after undergoing plastic deformation caused by the autofrettage process is significantly less than that predicted by the linear elastic theory of unloading. Kendall attributes this difference to the Bauschinger effect. The Bauschinger effect describes a phenomenon in which a material that has been plastically deformed in tension will have a reduced yield strength in compression. The stresses between the bore and the radius where $\sigma_r - \sigma_t = 0$ are changed due to the Bauschinger effect and

must be recalculated. These stresses are recalculated using equations which are derived by making the assumption that the difference between the circumferential and radial stresses is a linear function of the radius between the inner surface and the point at which this difference is equal to zero (as calculated from linear elastic unloading theory). Using the above assumption and considering the boundary conditions given below, the following relationship is obtained.

$$\sigma_{iR} - \sigma_{rr} = \sigma_{ic} - \frac{\sigma_{ic} (r - r_i)}{r_z - r_i} \quad (35)$$

Boundary conditions:

When $r=r_i$, $\sigma_{iR} - \sigma_{rr} = \sigma_{ic}$.

When $r=r_z$, $\sigma_{iR} - \sigma_{rr} = 0$.

where:

σ_{ic} = Corrected hoop stress at the bore

r_z = Radius where $\sigma_i - \sigma_r = 0$

σ_{iR} = Residual hoop stress

σ_{rr} = Residual radial stress

Combining (35) with (2) yields the following equation.

$$r d\sigma_{rr} = \sigma_{ic} dr + \frac{\sigma_{ic}}{r_z - r_i} r_i dr - \frac{\sigma_{ic}}{r_z - r_i} r dr \quad (36)$$

Integrating (36) yields the following equation.

$$\frac{\sigma_{rr}}{\sigma_{ic}} = \ln r + \frac{r_i \ln r}{r_z - r_i} - \frac{r}{r_z - r_i} + C \quad (37)$$

Where $r=r_i$, $\sigma_r=0$. This may be used to find the constant of integration.

$$C = \frac{r_i}{r_z - r_i} - \ln r_i - \frac{r_i \ln r_i}{r_z - r_i} \quad (38)$$

Substituting (38) into (37) yields the following expression for the radial stress in the cylinder from the inner surface to R_z .

$$\frac{\sigma_r}{\sigma_{ic}} = \frac{r_z \ln \left(\frac{r}{r_i} \right) + r_i - r}{r_z - r_i} \quad (39)$$

By substituting (39) into (2) the expression for circumferential stress for the same region is found to be the following.

$$\frac{\sigma_{tR}}{\sigma_{ic}} = \frac{r_z \left[\ln \left(\frac{r}{r_i} \right) + 1 \right] + r_i - 2r}{r_z - r_i} \quad (40)$$

The remaining residual stresses are calculated according to elastic unloading theory and are modified by a correction factor in order to assure continuity of the stresses at r_z . This correction factor is equal to the radial stress at r_z calculated using (39), divided by the radial stress at r_z calculated using elastic unloading theory. In order to make use of (39) and (40), a value for the corrected circumferential stress at the bore, σ_{ic} , must be found. Kendall(1) has proposed an empirically derived equation for this purpose.

$$\frac{\sigma_{ic}}{2\tau} = -B_f + C_h \left[\frac{\sigma_{iA}}{2\tau} + B_f \right] \quad (41a)$$

for

$$\sigma_{iA} < -0.8\tau \quad (41b)$$

If the criteria in (41b) is met, then the stresses need to be corrected for the Bauschinger effect. The constant B_f is the Bauschinger effect correction factor. The constant C_h takes in to account the strain hardening that takes place when the cylinder plastically deforms during unloading from the autofrettage pressure.

Operating Pressure Stress Calculation

The stresses caused by the pressure at which the vessel will be operating may be calculated using the elastic equations, (21) and (22). In the case of multiple cylinders the cylinders are treated as one large cylinder. These stresses are then superimposed on the residual stresses left from the autofrettage and shrinkfit. Yielding begins at $r = r_i$ when the following condition is met.

$$\sigma_\theta - \sigma_r = 2\tau \quad (42)$$

The radial stress at the bore is equal in magnitude to the operating pressure. The residual radial stress must be equal to zero in order to satisfy the boundary conditions before the operating pressure is applied. With the operating pressure applied the equation for the radial elastic stress

state of a thick walled cylinder, (21), at $r=r_i$ becomes the following.

$$\sigma_r = -p_d \quad (43)$$

Where p_d is the operating pressure.

The circumferential stress at the bore will be a superposition of the circumferential stress at the bore caused by the operating pressure added to the residual circumferential stress. The equation for the circumferential elastic stress state of a thick walled cylinder, (22) plus the residual circumferential stress, at $r=r_i$ becomes the following.

$$\sigma_\theta = \frac{r_o^2 + r_i^2}{r_o^2 - r_i^2} p_d + \sigma_{iR} \quad (44)$$

Substituting (43) and (44) into (42) the yield criteria may be expressed as follows.

$$p_d \left[\frac{r_o^2 + r_i^2}{r_o^2 - r_i^2} \right] + p_d = 2\tau - \sigma_{iR} \quad (45)$$

At the bore $r=r_i$. Substituting this condition into (45) yields the operating pressure at which reyielding will occur in the cylinder.

$$p_d = \frac{(2\tau - \sigma_{iR})(r_o^2 - r_i^2)}{2r_o^2} \quad (46)$$

If the cylinder re-yields during the unloading of the autofrettage pressure, then the residual circumferential stress at the bore must be modified according to (41). The yield strength is also modified and must be equal to the absolute value of the corrected residual circumferential stress at the bore. Putting these values into (46), the pressure at which re-yielding will occur may be expressed as follows.

$$p_d = \frac{2\tau (r_o^2 - r_i^2)}{r_o^2} \quad (47)$$

The factor of safety for the vessel, is based on the operating pressure and the ultimate strength of the vessel. The factor of safety is equal to the operating pressure divided by the ultimate strength of the vessel. Assuming that the material is perfectly plastic, the ultimate strength of the vessel is equal to the pressure necessary to cause complete yielding in the cylinder or cylinders. When yielding has proceeded completely through the cylinder, the residual stresses are relaxed and will not affect the calculation of the pressure necessary for complete yielding. Additionally it is known that $\sigma_r = 0$ at the outer surface of the cylinder. Since the cylinder is fully plastic the radial stress equation for the plastic zone of a cylinder, (6), may be used to calculate the pressure at which the cylinder will become fully plastic. Using $\sigma_r = 0$, $r = r_o$ in (6) yields the pressure at which the cylinder will become fully plastic.

$$p_i = k\tau \ln \left(\frac{r_o}{r_i} \right) \quad (48)$$

For nested cylinders in the fully plastic condition the interface pressure between the cylinders caused by the

shrinkfit will be relaxed along with the residual stresses from autofrettage. Thus the pressure at which multiple or nested cylinders will be fully plastic is simply the sum of the pressures necessary to make each individual cylinder fully plastic.

$$p_i = \sum k\tau \ln \left(\frac{r_o}{r_i} \right) \quad (49)$$

Chapter III

Definition of the Software's Purpose

Solvable Problem Types

There are three types of problems that may be solved using this software; single cylinder autofrettage process, two cylinders with shrinkfit process only, and two cylinders with autofrettage and shrinkfitting processes. All of these problem types include the application of an internal operating pressure. The stresses are calculated by applying the equations from part one of this thesis over a discrete mesh. The number of nodes in the mesh may be defined by the user.

For single cylinder autofrettage only, the user supplies either the depth of yielding or the autofrettage pressure and the software calculates the other one. The next step is to calculate the stresses caused by the application of the autofrettage pressure. The stress state in the plastic zone, from the bore to the depth of yielding, is calculated using (6) and (7). The stress state in the elastic zone, from the depth of yielding to the outer surface, is calculated using (12) and (13). Next the stresses caused when the autofrettage pressure is released are calculated using the elastic equations, (12) and (13). The stresses caused by the application of the autofrettage pressure are superimposed on the stresses caused by the release of the autofrettage pressure in order to obtain the residual stress state after the autofrettage process. This stress state is then checked to see if a correction due to the Bauschinger effect is required. If the criteria given in

(41a) for a correction is met, then the software recalculates the stresses according the the method outlined in the section titled, "The Bauschinger Effect".

For a two cylinder problem with only the shrinkfitting process, the user must supply the amount of the interference in the fit of the two cylinders. The software then calculates the interface pressure that is caused by this shrink fit. The stress state is calculated using the elastic equations, (12) and (13).

For a two cylinder problem with the autofrettage process and the shrink fitting process, the residual stress state for the inner cylinder is calculated in the same manner as a one cylinder problem with autofrettage only. The stresses caused by the shrinkfit are calculated in the same manner as for a two cylinder, shrinkfit only problem. These shrink fit stresses are superimposed on the residual autofrettage stresses and this total residual stress state is checked to see if a correction for the Bauschinger effect is necessary. If the criteria for a correction is met, then the software recalculates the stresses according the method outlined in the section titled, "The Bauschinger Effect".

For all of the above problem types the software then calculates the stresses caused by the application of the operating pressure and superimposes them on the residual stress state. The factor of safety is calculated and the stress state is checked to insure that the vessel does not plastically deform upon the application of the operating pressure. If the vessel does undergo plastic deformation when the operating pressure is applied the software will alert the user so that the appropriate redesign of the pressure vessel may be implemented.

Required Input and the Resulting Output

The following section lists the required input values for each type of problem and the output that the software generates.

Single cylinder, autofrettage process only:

Input:

1. Inner radius for inner cylinder.
2. Outer radius for inner cylinder.
3. Yield stress of vessel material.
4. Depth of plastic deformation,
or
the autofrettage pressure.
5. The operating pressure

Output:

1. Autofrettage pressure at which plastic deformation will begin at the bore.
2. Autofrettage pressure at which the vessel will undergo plastic deformation from the bore to the outer surface.
3. Depth of plastic deformation,
or
the autofrettage pressure.
(Whichever is not given as input.)
4. Operating pressure at which reyielding will occur.
5. Factor of safety based on operating pressure.
6. The following stress graphs are drawn for radial and circumferential stresses.
 - A. Residual stress state after the autofrettage pressure is released.

- B. Stress state caused by the application of the operating pressure.
- C. Total stress state caused by the autofrettage process and the operating pressure.
- 7. The tabular form of the following stress arrays for radial and circumferential stresses may be examined or printed.
 - A. Stresses caused by application of autofrettage pressure.
 - B. Residual stresses after the autofrettage pressure is released.
 - C. Stresses caused by the application of the operating pressure.
 - D. Total stresses caused by the autofrettage and the operating pressure.

Two cylinders, shrinkfit process only:

Input:

- 1. Inner radius for inner cylinder.
- 2. Outer radius for inner cylinder.
- 3. Inner radius for outer cylinder.
- 4. Outer radius for outer cylinder.
- 5. Yield stress of vessel material for inner cylinder.
- 6. Yield stress of vessel material for outer cylinder.
- 7. Amount of interference between the cylinders for the shrinkfit process.
- 8. Poisson's ratio for inner and outer cylinder.
- 9. The operating pressure.

Output:

1. Interface pressure caused by the shrinkfit.
2. Operating pressure at which yielding will occur.
3. Factor of safety based on operating pressure.
4. The following stress graphs are drawn for radial and circumferential stresses.
 - A. Stress state caused by the shrinkfit between the two cylinders.
 - B. Stress state caused by the application of the operating pressure.
 - C. Total stress state caused by the shrink fit and the operating pressure.
5. The tabular form of the following stress arrays for radial and circumferential stresses may be examined or printed.
 - A. Stresses caused by shrinkfit.
 - B. Stresses caused by the application of the operating pressure.
 - C. Total stresses caused by the shrinkfit and the operating pressure.

Two cylinders, autofrettage and shrinkfit process:

Input:

1. Inner radius for inner cylinder.
2. Outer radius for inner cylinder.
3. Inner radius for outer cylinder.
4. Outer radius for outer cylinder.
5. Yield stress of vessel material for inner cylinder.

6. Yield stress of vessel material for outer cylinder.
7. Depth of plastic deformation
or
the autofrettage pressure
8. Amount of interference between the cylinders for the shrinkfit process.
9. Poisson's ratio for inner and outer cylinder.
10. The operating pressure.

Output:

1. Autofrettage pressure at which plastic deformation will begin at the bore.
2. Autofrettage pressure at which the vessel will undergo plastic deformation from the bore to the outer surface.
3. Depth of plastic deformation
or
the autofrettage pressure.
(Whichever is not given as input.)
4. Interface pressure caused by the shrinkfit.
5. Operating pressure at which reyielding will occur.
6. Factor of safety based on operating pressure.
7. The following stress graphs are drawn for radial and circumferential stresses.
 - A. Stress caused by application of autofrettage pressure.
 - B. Residual stress after the autofrettage pressure is released.
 - C. Stress state caused by the shrinkfit between the two cylinders.
 - D. Total stress state caused by the shrink fit and the autofrettage.

- E. Stress state caused by the application of the operating pressure.
 - F. Total stress state caused by the autofrettage, shrinkfit and the operating pressure.
8. The tabular form of the following stress arrays for radial and circumferential stresses may be examined or printed.
- A. Stresses caused by application of autofrettage pressure.
 - B. Residual stresses after the autofrettage pressure is released.
 - C. Stresses caused by shrinkfit.
 - D. Combined stresses caused by the shrinkfit and the autofrettage.
 - E. Stresses caused by the application of the operating pressure.
 - F. Total stresses caused by the autofrettage, shrinkfit and the operating pressure.

Chapter IV

Solution of an Example Problem

An example problem is solved and the appropriate output windows for each step are shown in this section. Also the report that is generated by selecting "Print Report" from the "Report" menu shall be shown. In order to run the sample problem, the following steps should be followed:

1. Turn on the Macintosh.
2. Insert the Under Pressure disk.
3. Double-click the Under Pressure folder.
4. Double-click the Under Pressure icon.

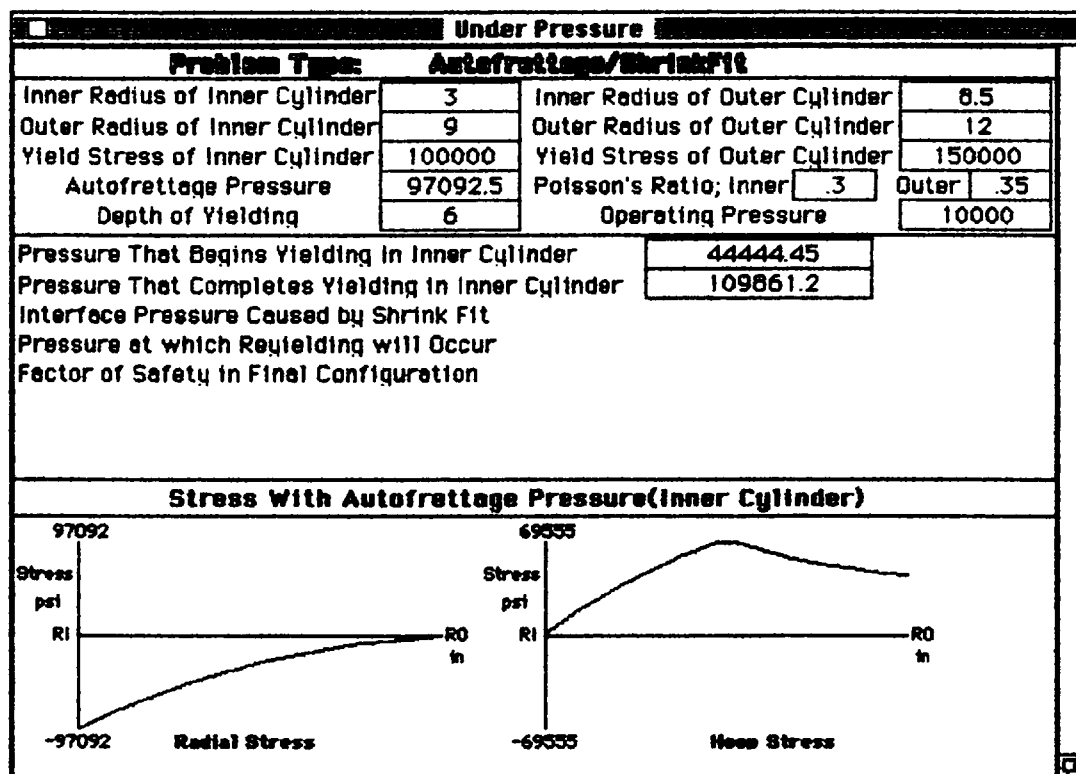
In a few seconds, the following window will appear:

Problem Type: Autofrettage/Shrink Fit	
Inner Radius of Inner Cylinder	Inner Radius of Outer Cylinder
Outer Radius of Inner Cylinder	Outer Radius of Outer Cylinder
Yield Stress of Inner Cylinder	Yield Stress of Outer Cylinder
Autofrettage Pressure	Poisson's Ratio; Inner Outer
Depth of Yielding	Operating Pressure
Pressure That Begins Yielding in Inner Cylinder Pressure That Completes Yielding in Inner Cylinder Interface Pressure Caused by Shrink Fit Pressure at which Reyielding will Occur Factor of Safety in Final Configuration	

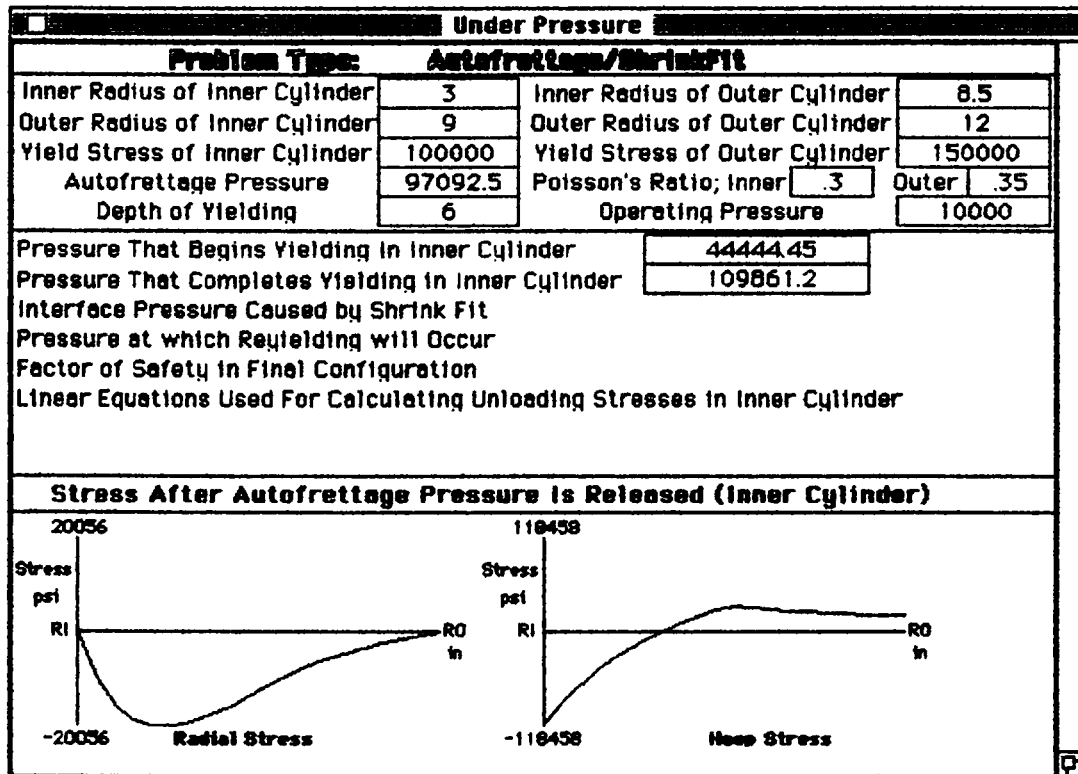
The problem information may be entered by clicking the mouse in the rectangular fields. For example, the inner radius of the inner cylinder is entered in the rectangular field following the label, "Inner Radius of Inner Cylinder". Movement between the fields may be accomplished by clicking the mouse in the appropriate fields, or by using the tab key. Input information may also be loaded into the program by selecting "Open Old Data" from the "File" menu. The data for this problem is contained in the file called "A Sample Problem" and is located in the folder named "Under Pressure". The default units are pounds per square inch for pressures and stresses, and inches for radii, depth of yielding, and shrinkfit amount. These may be changed to SI units by using the "Units" menu. When the input information is entered or loaded, the screen will appear as follows:

Under Pressure			
Problem Type:		Autofrettage/ShrinkFit	
Inner Radius of Inner Cylinder	3	Inner Radius of Outer Cylinder	8.5
Outer Radius of Inner Cylinder	9	Outer Radius of Outer Cylinder	12
Yield Stress of Inner Cylinder	100000	Yield Stress of Outer Cylinder	150000
Autofrettage Pressure	97092.5	Poisson's Ratio; Inner	.3
Depth of Yielding	6	Operating Pressure	10000
Pressure That Begins Yielding in Inner Cylinder Pressure That Completes Yielding in Inner Cylinder Interface Pressure Caused by Shrink Fit Pressure at which Reyielding will Occur Factor of Safety in Final Configuration			

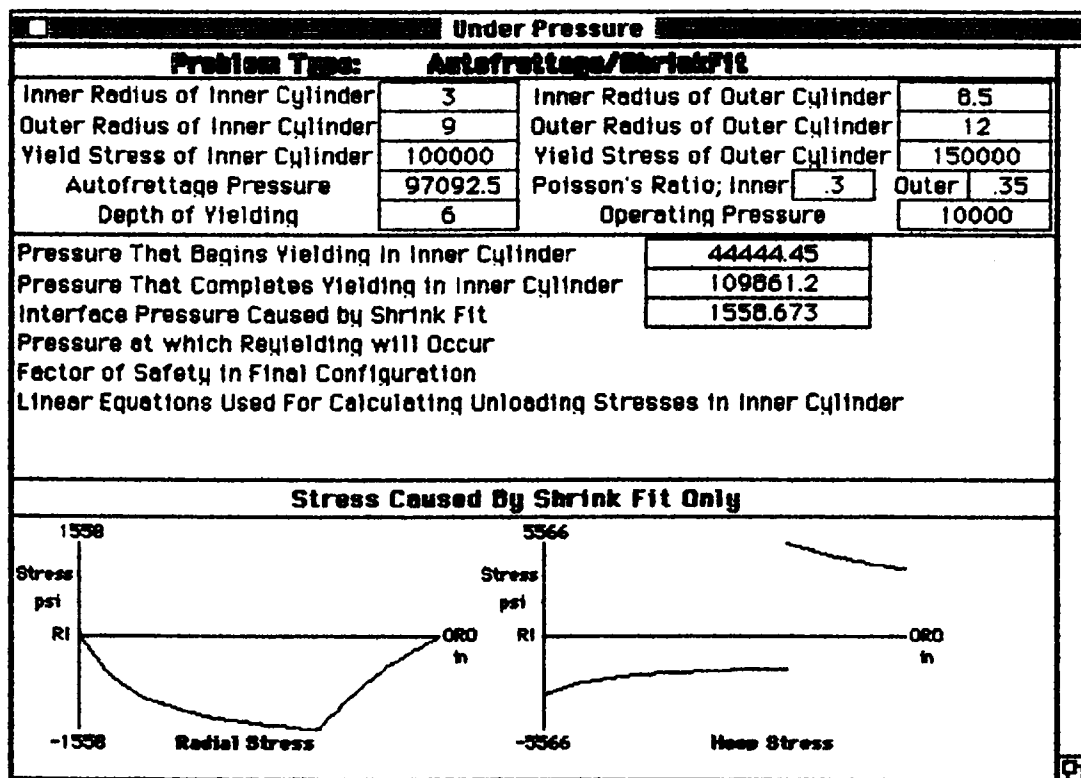
The default problem type is autofrettage and shrinkfit of two cylinders. The problem type may be changed under the "AutoP" menu. For this example the problem type will not be changed. First the stress state produced by the application of the autofrettage pressure will be calculated. This is done by selecting "Stress With Autofrettage Pressure" from the "Stress" menu. This will produce the following output window.



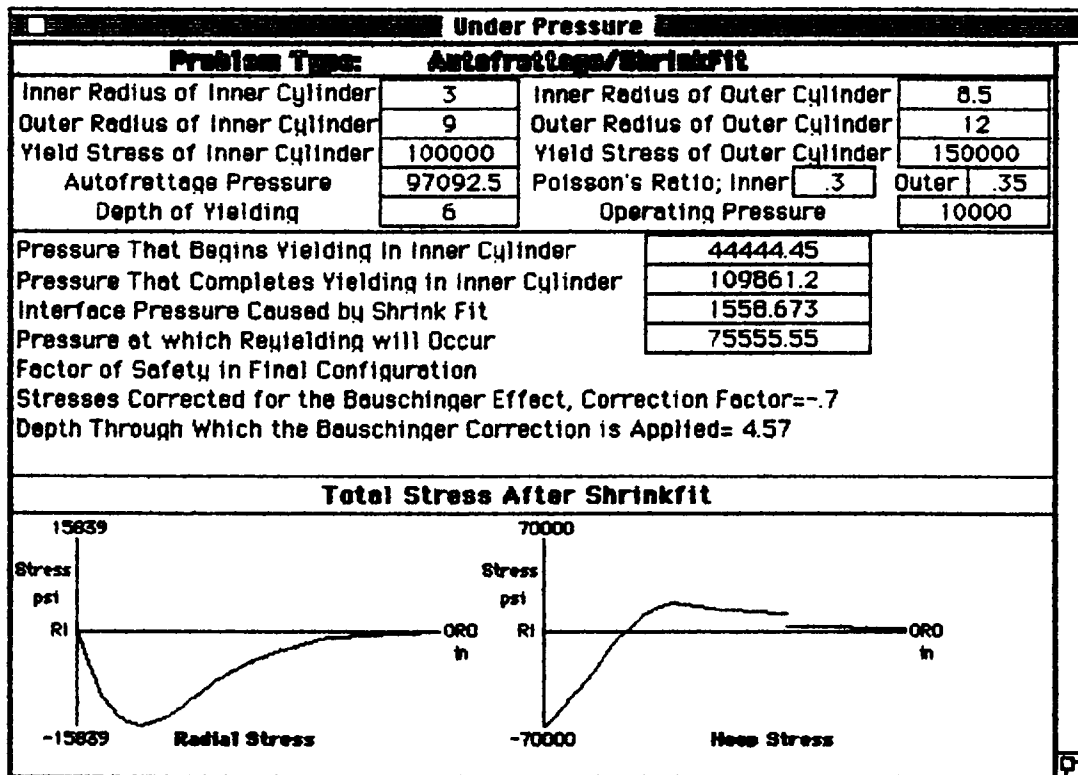
In order to calculate the residual stresses after the autofrettage pressure is released select "Residual Stress After Autofrettage (Inner Cylinder)" from the "Stress" menu. The screen should now appear as follows:



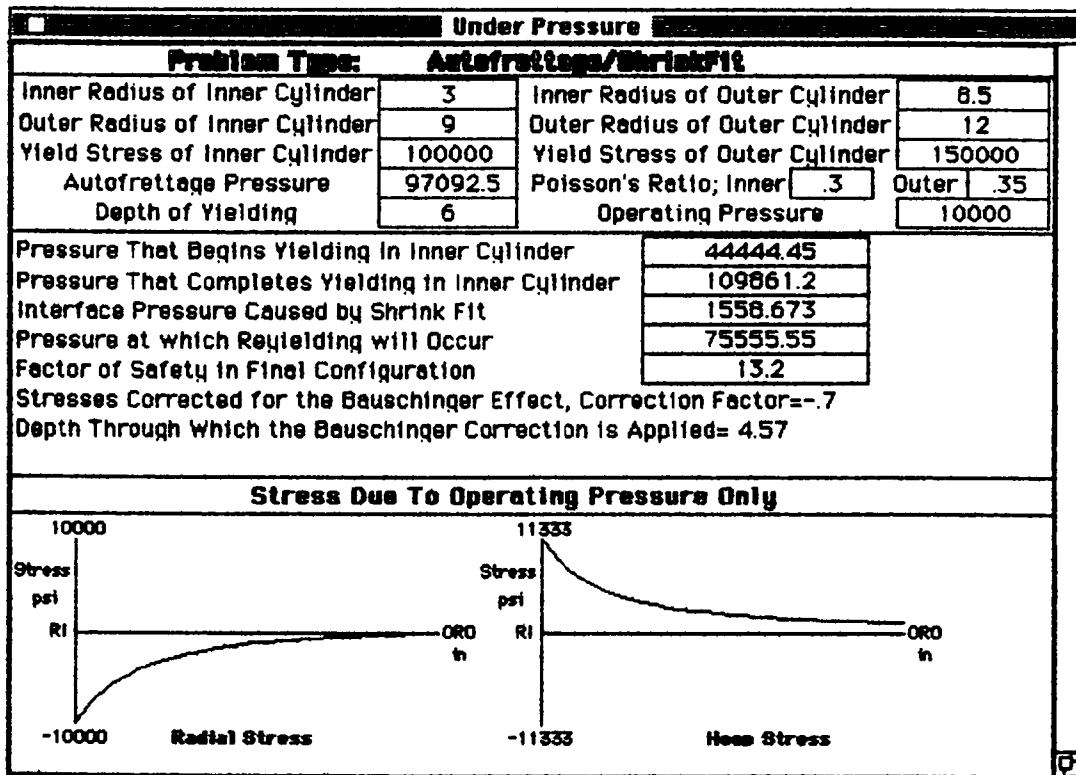
Next the stresses caused by the shrinkfitting process may be calculated by selecting the "Stress due to Shrinkfit Only" option from the "Stress" menu. This will calculate the stresses caused by the shrinkfitting process only, as if the autofrettage process had not taken place. The output window should now appear as follows:



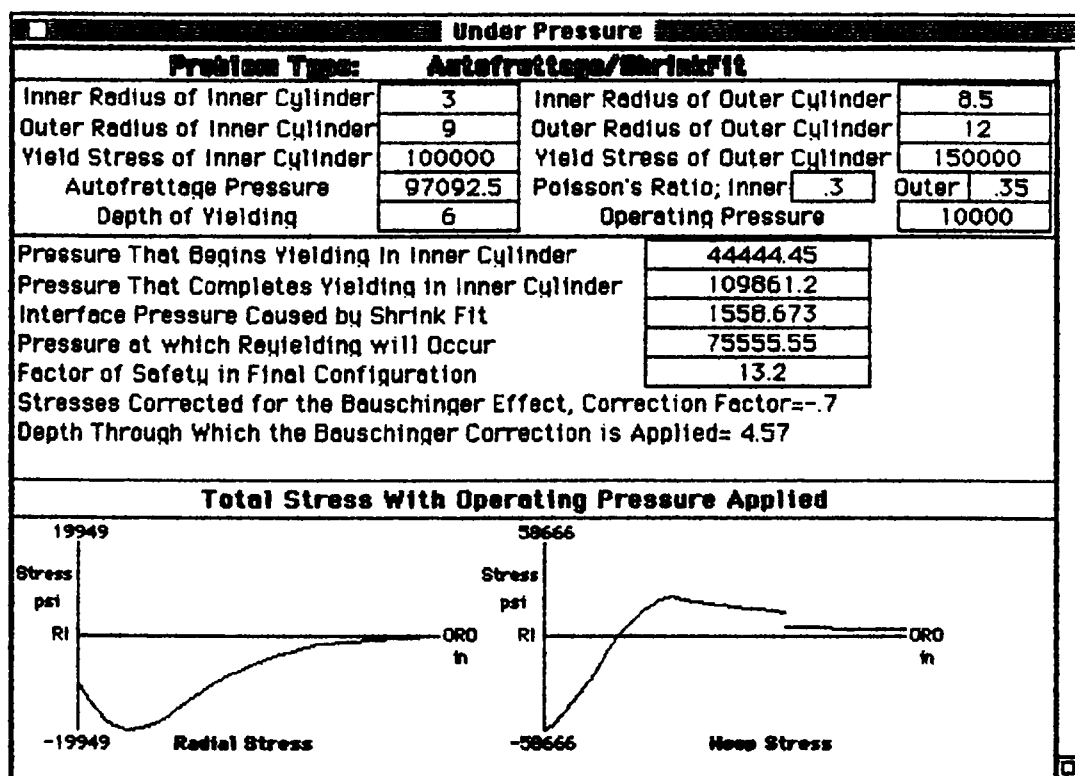
The stress state including the stresses caused by the autofrettage and shrinkfitting processes is calculated by selecting the "Total Stress After Shrinkfit" option from the "Stress" menu. This will produce the following output window:



Next the stress state caused by the application of the operating pressure can be calculated by selecting the "Stress From Operating Pressure Only" option from the "Stress" menu. This will calculate the stress state caused by the operating pressure only, as if the autofrettage and shrinkfit had not been performed. The following output window will result from this selection:



Now the stress state of the final configuration of the pressure vessel with the operating pressure applied may be calculated by selecting the "Total Stress With Operating Pressure" option from the "Stress" menu. This will result in the following output window:



A complete report for the problem may be generated by selecting the "Print Report" option from the "Report" menu. This will produce the report which appears exactly as the next five pages.

Stress Analysis Report

Stress Analysis for Autofrettage, Shrinkfit and Operating Pressure of Two Cylinders

Inner Radius of Inner Cylinder = 3 in
Outer Radius of Inner Cylinder = 9 in
Inner Radius of Outer Cylinder = 8.5 in
Outer Radius of Outer Cylinder = 12 in
Yield Stress in Tension of Inner Cylinder = 100000 psi
Yield Stress in Tension of Outer Cylinder = 150000 psi
Poisson's Ratio of Inner Cylinder = .3
Poisson's Ratio of Outer Cylinder = .35
Pressure at Which Yielding Begins at the Bore of Inner Cylinder= 44444 psi
Pressure at Which the Inner Cylinder is Completely Yielded = 109861 psi
Autofrettage Pressure= 97092 psi
Depth of Yielding Caused by the Autofrettage Pressure= 6 in
Operating Pressure= 10000 psi
Interface Pressure Caused by the Shrinkfit=1558 psi
Pressure at Which Yielding Will Reoccur at the Bore = 75555 psi
Factor of Safety = 13.2

A correction due to the Bauschinger effect was used in the calculation of the stresses caused by the release of the autofrettage pressure.

Stresses in Inner Cylinder With the Autofrettage Pressure Applied

Radial stress at the bore = -97092 psi
Hoop stress at the bore = 2907 psi
Radial stress at the outer surface = 0 psi
Hoop stress at the outer surface = 44339 psi
Maximum radial stress = -97092 psi
Maximum hoop stress = 69555 psi

Residual Stresses in Inner Cylinder After Autofrettage Pressure

Radial stress at the bore = 0 psi
Hoop stress at the bore = -118458 psi
Radial stress at the outer surface = 0 psi
Hoop stress at the outer surface = 20065 psi
Maximum radial stress = -20056 psi
Maximum hoop stress = -118458 psi

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Total Residual Stress After the Shrinkfit

Stresses in Inner Cylinder

Radial stress at the bore = 0 psi
Hoop stress at the bore = -70000 psi
Radial stress at the outer surface = -1172 psi
Hoop stress at the outer surface = 13628 psi
Maximum radial stress = -15839 psi
Maximum hoop stress = -70000 psi

Stresses in Outer Cylinder

Radial stress at the bore = -1172 psi
Hoop stress at the bore = 4187 psi
Radial stress at the outer surface = 0 psi
Hoop stress at the outer surface = 3014 psi
Maximum radial stress = -1172 psi
Maximum hoop stress = 4187 psi

Stresses Caused by Operating Pressure Only

Stresses in the Inner Cylinder

Radial stress at the bore = -10000 psi
Hoop stress at the bore = 11333 psi
Radial stress at the outer surface = -518 psi
Hoop stress at the outer surface = 1851 psi
Maximum radial stress = -10000 psi
Maximum hoop stress = 11333 psi

Stresses in the Outer Cylinder

Radial stress at the bore = -518 psi
Hoop stress at the bore = 1851 psi
Radial stress at the outer surface = 0 psi
Hoop stress at the outer surface = 1333 psi
Maximum radial stress = -518 psi
Maximum hoop stress = 1851 psi

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Total Stress State With Operating Pressure Applied

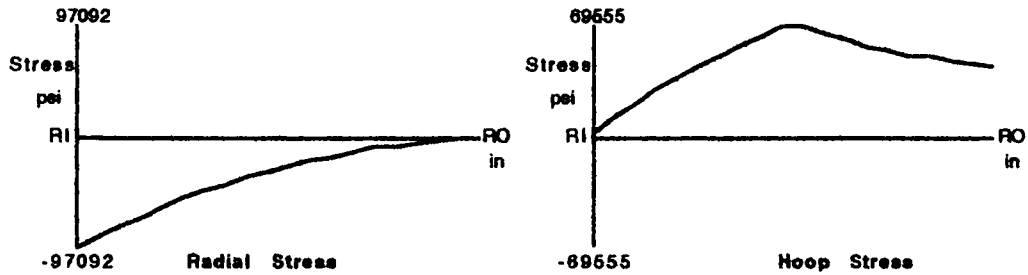
Stresses in the Inner Cylinder

Radial stress at the bore = -10000 psi
Hoop stress at the bore = -58666 psi
Radial stress at the outer surface = -1690 psi
Hoop stress at the outer surface = 15480 psi
Maximum radial stress = -19949 psi
Maximum hoop stress = -58666 psi

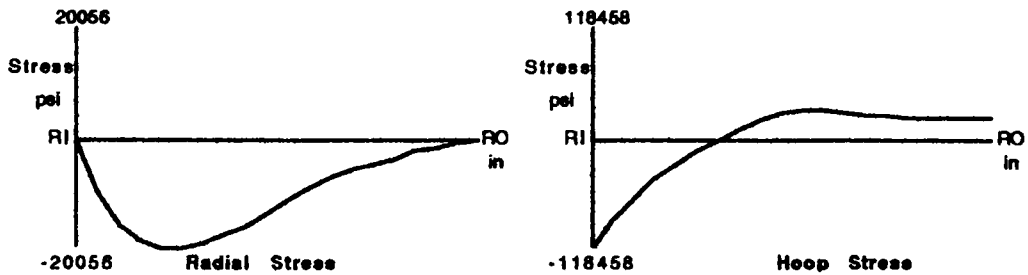
Stresses in the Outer Cylinder

Radial stress at the bore = -1690 psi
Hoop stress at the bore = 6039 psi
Radial stress at the outer surface = 0 psi
Hoop stress at the outer surface = 4348 psi
Maximum radial stress = -1690 psi
Maximum hoop stress = 6039 psi

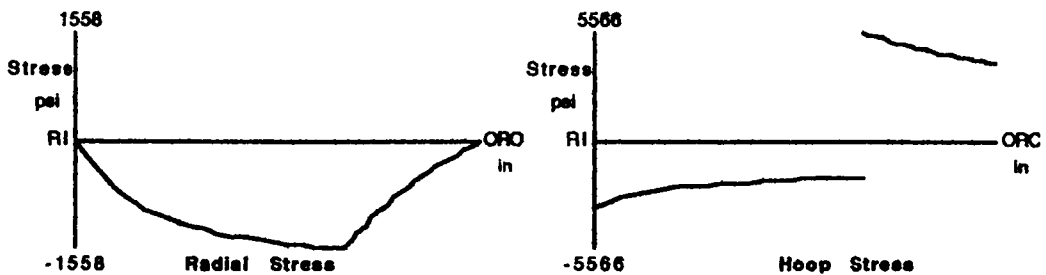
Stress With Autofrettage Pressure (Inner Cylinder)



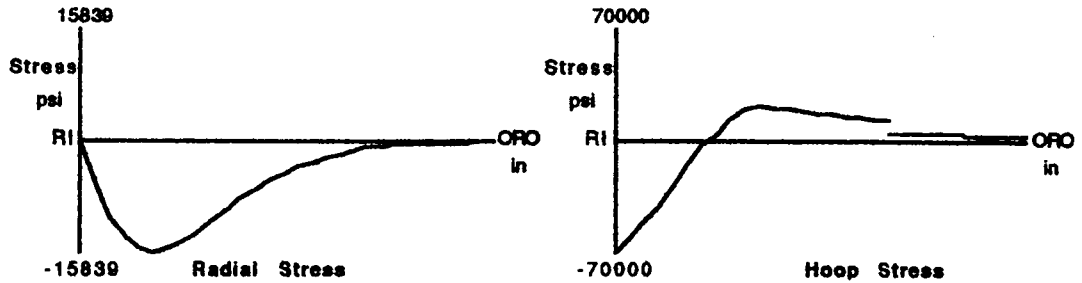
Stress After Autofrettage Pressure Is Released (Inner Cylinder)



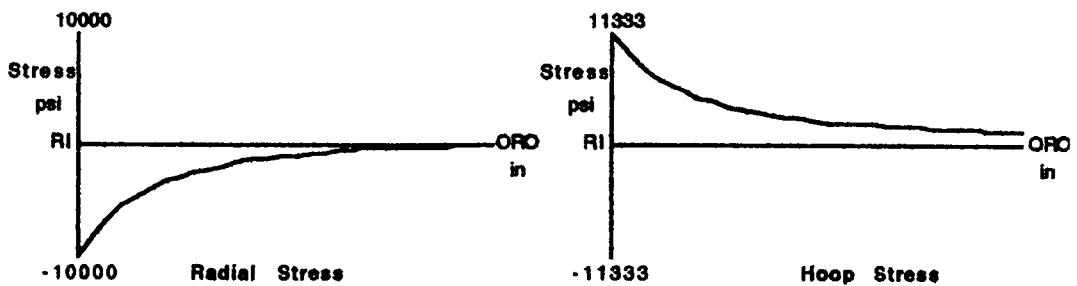
Stress Caused By Shrink Fit Only



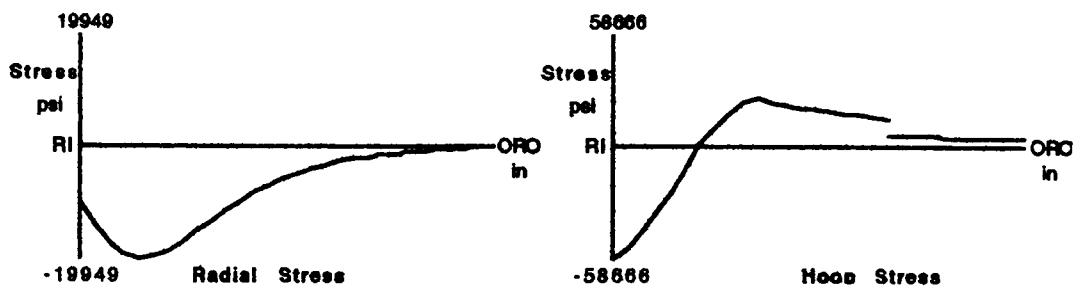
Total Stress After Shrinkfit



Stress Due To Operating Pressure Only



Total Stress With Operating Pressure Applied



Chapter V

Discussion and Conclusion

Manufacture of high pressure vessels usually requires prestressing the vessel to induce a state of compressive residual stress. This prestressing takes one of two forms. The autofrettage process induces a residual stress state by means of an internal pressure which causes partial yielding of the vessel. Shrinkfitting two vessels with an interference fit will also induce compressive residual stresses at the inside of the smaller vessel.

The design of these types of vessels involves a large number of calculations. The process of designing such vessels is therefore lengthy and time consuming. There are also many opportunities for the designer to make errors, given the large number of calculations involved. For these reasons a automated solution to this problem is desirable.

In order for the designer to test a design, the following must be done. First the residual stresses from the autofrettage process must be calculated. There are two steps in the calculation of the residual stresses caused by the autofrettage process. First the stresses caused by the application of the autofrettage pressure must be calculated. When the autofrettage pressure is applied, the cylinder will yield forming a zone in which plastic flow has occurred. The stresses in this zone are calculated using the plastic stress equations. The stresses in the remainder of the cylinder may be calculated using the elastic equations. Next the stresses that are caused by the release of the autofrettage pressure are calculated. The cylinder may reyield during the unloading of the autofrettage pressure.

If this occurs, the stresses in the reyielded zone must be recalculated. The reyielding pressure has been experimentally shown to be much less than predicted by the elastic stress equations. This is known as the Bauschinger effect and must be considered in order to properly calculate the stresses in the reyielded zone. These stresses are superimposed on the stresses caused by the application of the autofrettage pressure, yielding the residual stress state of the cylinder. If the problem being solved is a single cylinder autofrettage, then the stresses caused by the application of the operating pressure are superimposed on the residual stresses to give the final stress state of the cylinder.

For the multilayered vessel the stresses caused by shrink fitting the outer cylinder onto the inner cylinder are superimposed onto the residual stresses caused by the autofrettage. The shrink fit stresses are calculated by determining the interface pressure caused by the shrink fit, and using this pressure in the elastic stress equations. The final stress state is determined by superposition of the stresses caused by the application of the operating pressure.

As stated above, an automated solution to this problem is desirable. That is the purpose of this thesis. The advantages and requirements of a computer solution are many. The speed and accuracy of the solution of many types of engineering problems may be greatly enhanced by the use of computers. Properly designed software should be easy to learn and use, yet should also be flexible enough to meet all of the engineer's needs. These needs include the ability to solve as many different types of problems as possible. If the software is too limited in scope, it will not be widely useful. In addition, the software should have the ability to generate reports with minimal effort from the user. Since a

standardized report will not always meet the user's needs, custom report generation is a feature that many users will find useful. The Under Pressure software provides a wide array of options for solving problems, along with very thorough report generation capabilities. The Under Pressure software will generate a standard report for each problem solved. It will also produce text files of the standard report, and of the stresses at each individual mesh point. These text files may be edited using a word processing program. This allows the user to generate custom reports with a minimum of effort. The use of the Under Pressure software should greatly reduce the amount of time an engineer spends developing and documenting designs of cylindrical high pressure vessels.

The process of developing this software has been very challenging. The construction of a software package that delivers a high degree of functionality while maintaining a user friendly interface is an complex problem. It requires the development of many programming skills. Among these are ability to organize large sections of code, so that the program execution is as efficient as possible. It also requires a Macintosh programmer's approach to using events, edit fields, menus, and icons. Events allow the user to communicate with the software in a much more intuitive fashion than with a command line interface. Events consist of, but are not limited to, selection of a menu option, clicking the mouse in an edit field, or selecting a button. The program waits for an event to occur, and then branches to the appropriate section of code. This allows the user to select options in an more efficient manner than with a command line interface. Edit fields are rectangular areas in the window where text or numeric data may be entered. Each edit field is associated with a particular variable in the program. The user may change a particular variable by using

the mouse to locate the cursor in the edit field and typing the new value. The next time the user selects a menu option, the new value from the edit field is used in the calculations. This is useful because it allows the user to enter or change data without restarting the software or editing a data file. Menus allow the user to select the desired option without "visiting" a large number of screens. The use of edit fields, menus and events, allow the user to test many configurations of a problem in a much shorter period of time than with a command line software package. Using these items it is possible to construct software which is much easier for the user to learn. Icons allow for simplified manipulation of the data files that are created by the program.

There were many problems that were overcome during the development of this software. Learning to manipulate graphics was the biggest challenge. The graphs produced by the program had to be stored in array form, sent to the printer, transferred to the clipboard, or manipulated on the screen. The clipboard is a standard feature on Macintosh computers and is used to transfer text or graphics between various programs. The stress graphs or the current window from Under Pressure may be copied to the clipboard. This allows the user to generate custom reports that include graphics. Preparing the Under Pressure program has greatly improved the author's ability to develop large, user friendly software packages.

References

References

1. Kendall, D. P. 1987. "The Influence of The Bauschinger Effect On the Re-Yielding Of Autofrettaged Thick-Walled Cylinders." In ASME PVP, Volume 125, Troy, New York: Press-Quench Enterprises. pp. 17-21.
2. Cook, Robert D. and Warren C. Young. 1985. Advanced Mechanics of Materials. New York: Macmillan Publishing Company.
3. James, M. L. 1985. Applied Numerical Methods for Digital Computation. New York: Harper and Row.
4. Microsoft. 1986 Microsoft Quickbasic Users Guide. Houston, Tx: Microsoft Corporation.
5. Den Hartog, J. P. 1949. Strength Of Materials. New York: Dover Publications Inc.
6. Alley, Peter. and Carolyn Strange. 1991. ResEdit Complete. Reading, Massachusetts: Addison-Wesley.

Appendices

Appendix A

The Bisection Routine.

The bisection routine is a method for finding real roots of equations of the form, $f(r_p)=0$. In the autofrettage problem it is necessary to determine the depth of yielding in a thick walled cylinder caused by a given internal pressure. The equation for which the roots are to be solved has the form:

$$f(r_p) = k\tau \left[\left(\ln \frac{r_p}{r_i} \right) + \left(\frac{r_o^2 - r_p^2}{2r_o^2} \right) \right] - p_{auto} = 0 \quad (25)$$

In this problem it is not necessary to guess an initial interval in which to search for the root, since if the cylinder yields, the depth of yielding must lie between the inner and outer radii of the cylinder. Further, the program only branches to the bisection routine if the internal pressure is greater than that which will cause yielding to begin at the bore of the cylinder, thus it is known that the root exists. Knowing the interval to be searched, and that the root exists, all that is left to do is to find the root. The bisection routine operates by dividing the interval to be searched into two equal parts. In this case the intervals would consist of; the inner radius to halfway through the cylinder, and halfway through the cylinder to the outer surface. The bisection routine then evaluates the function at the endpoints of each interval. The first interval lies between $r=r_i$ and $r=(r_o+r_i)/2$, the second interval lies between

$r = (r_o + r_i)/2$ and $r = r_o$. If the function values for an intervals endpoints have different signs, that is, one is positive and the other negative, this indicates that the root lies in this interval. This new interval is then operated on in the same method as the original interval, and this process is continued until the function value is very close to zero. The value of r at this location is the root, which in this problem is the depth of yielding.

Appendix B

The Users Guide

Under Pressure may be run on any Macintosh Plus or later model. Under Pressure requires System and Finder versions no earlier than System 4.1 and Finder 5.5. This users guide describes the operation of the Under Pressure software. It assumes that the reader has a basic understanding of how to use menus, scrolling, text and a mouse. For information on these subjects please consult your Macintosh user manuals. Under pressure may be run from either a hard drive or from floppy disk.

To use Under Pressure, use the following procedure:

1. Turn on your Macintosh.
2. Put the Under Pressure disk into your Macintosh.
3. If you are going to run Under Pressure from a hard drive, copy the Under Pressure folder onto your hard drive.
4. Double-click the Under Pressure folder.
5. Double-click the Under Pressure icon.

This section will describe how to get started with a sample problem.

1. Start Under Pressure.
2. Go to the File menu and select "Open Old Data".
3. Find the file "First Pressure Problem", which is located in the Data folder, which is inside of the Under Pressure folder.

4. Double-click on the file, or select it and press the open button. This will load the sample problem data into the program.
5. Select "Residual Stress after Autofrettage (Inner Cylinder)" from the stress menu. This will display the pressure at which yielding begins, the pressure at which yielding is complete, the autofrettage pressure required to produce the given depth of yielding, and graphs of the stress state in the cylinder.
6. You may now select other options from the menu bar.

Solving Problems

The First step in solving problems is to enter the problem data. If it is an autofrettage only problem, the dimensions of the inner cylinder, the tensile yield strength of the inner cylinder, and the operating pressure are required as input. For shrinkfit problems and problems including both autofrettage and shrinkfit, the dimensions of both cylinders, yield strengths of both cylinders, Poisson's ratio for both cylinders, and the operating pressure are required as input. This may be done in two ways. The first is to enter the data in the fields of the main window of Under Pressure. These fields are the small squares following the description of the data to be entered. The first one is "Inner Radius of Inner Cylinder". The datum is entered by clicking in the field, then entering the corresponding value. Moving between fields is accomplished by using the mouse or tab key. The length data is entered in inches for the English mode or millimeters for the SI mode. The pressure and yield strength data are entered in psi in the

English mode or MPa in the SI mode. The Second method of entering data is by using the "File" menu and selecting "Input Old Data". This will bring up the standard Macintosh file dialog box, in which the file to be opened may be selected. When the file is opened, Under Pressure will automatically insert the data into the proper fields.

Next, the program must be informed which of the two values the user supplies, autofrettage pressure or depth of yielding. This is done by going to the "AutoP" menu and selecting either "User Supplies Autofrettage Pressure" or "User Supplies Depth of Yielding". The current choice is indicated by a check mark in the menu.

Once the above steps are completed, the type of problem being solved must be selected. This is done by going to the "AutoP" menu and selecting one of the following: "Autofrettage Only" for single cylinder autofrettage process, "Shrinkfit Only", for two cylinder shrinkfit process with no autofrettage, or "Shrinkfit and Autofrettage" for two cylinder problems involving shrinkfit and autofrettage processes. Again the current selection is indicated by a checkmark.

Next the yield criteria must be selected from the yield criteria menu. There are two options, Tresca theory and von Mises theory. The currently selected theory of failure is indicated by a checkmark. The Tresca theory of failure states that an isotropic material will begin to yield when the maximum shear stress reaches a limiting value. The von Mises theory of failure states that an isotropic material will begin to yield when the effective stress reaches a limiting value. The effective stress may be expressed as follows.

$$\sigma_e = \frac{1}{\sqrt{2}} [(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)]^{1/2} \quad (50)$$

There are two choices for units, the SI system and the English system. In the SI system the pressures, stresses and yield strengths are given in MPa and the lengths are given in mm. In the English system the pressures, stresses and yield strengths are given in psi and the lengths are given in inches. The selection of units is made in the "Units" menu, with the current choice indicated by a checkmark in the menubar.

The number of discrete points that the stresses are calculated at is set by selecting Number of Nodes from the "Mesh" menu. When Number of nodes is selected, a window appears with the current number of nodes in the inner and outer cylinders. These may be changed by positioning the cursor in the fields and changing the numbers. After the number of nodes is changed, click the OK button.

The stress state of the problem you have entered may now be calculated. For problems involving autofrettage, go to the "Stress" menu and select either "Stress With Autofrettage Pressure" or "Residual Stress After Autofrettage". This will calculate the pressure at which plastic deformation begins in the cylinder, the pressure at which the cylinder is completely plastic, and the depth of yielding or the autofrettage pressure. Graphs of the radial and circumferential stress states will also be displayed in the window. If the problem involves a shrinkfit, go to the stress menu and select one of the shrinkfit options. The last step in the calculations is the stress state caused by the operating pressure. This is calculated by selecting one of the operating pressure options in the Stress menu. By modifying the input data it is possible to find the configuration of the pressure vessels that will best meet the design criteria. The stresses at the discrete points in

the cylinders may be examined by selecting "Examine Tabular Form of Stress Arrays" from the "Report" menu.

Reports

Now that the problem is solved a report may be generated by selecting "Print Report" from the report menu. This will print a standard report of the specifications of the design and the stresses at various points. It will also include all relevant stress graphs. For developing custom reports there are several options. The current screen may be printed by selecting "Print This Screen" from the "Report" menu. The stresses at all of the discrete points may be sent to the printer, or written to a text file for use in a word processing program, by selecting "Print Tabular Form of Stress Arrays" or "Write Text File of Stress Arrays" in the Report menu. Also the report that is generated by the "Print Report" option may be written to a file for use in a word processing program, by selecting the option "Create Report File" in the "Report" menu. This file will not include the stress graphs, as most word processors have different methods for storing graphics. The graphs may be transferred to most word processors through use of the clipboard. To achieve this, simply select the "Copy Graph to Clipboard" option in the edit menu, start the word processing program and paste it in the proper location. The graph that is copied to the clipboard, is the graph that appears on the screen when the selection "Copy Graph To Clipboard" is made.

Menus

File Menu

Save Current Data

Takes the current input data and saves it in a text file.

Open Old Data

Opens a previously created data file and loads these values into the program.

Help

Displays on line help.

Quit

Stops execution of program.

Edit

Save Graph to Clipboard

Takes the current graph and pastes it onto the clipboard, for use in custom report generation.

Report

Print This Screen

Sends the current screen to the printer.

Print Report

Sends a complete report including input data and stress graphs to the printer.

Write Text File of Stress Arrays

Creates an ASCII text file of the stresses at each individual mesh point, with headings, for use in custom report generation.

Print Tabular Form of Stress Arrays

Sends stresses at each individual mesh point with headings to the printer.

Examine Tabular Form of Stress Arrays

Allows user to examine the stresses calculated at each individual mesh point in a scrollable window.

Create Report File

Writes report to a text file for use in custom report generation.

Yield Criteria

Tresca

Selects the Tresca yield criteria for use in the calculation of the stress state.

Von Mises

Selects the Von Mises yield criteria for use in the calculation of the stress state.

AutoP

User Supplies Autofrettage Pressure

When this option is chosen the user must supply the autofrettage pressure and the program will calculate the depth of yielding.

User Supplies Depth of Yielding

When this option is chosen the user must supply the depth of yielding and the program will calculate the autofrettage pressure.

Calculate Autofrettage Pressure

With this option the program will calculate the autofrettage pressure for a given depth of yielding without calculating the entire stress state in the pressure vessel.

Calculate Pressure at Which Yielding Begins and Ends in the Cylinder

This option calculates the pressure at which plastic deformation will begin in the inner cylinder, and the pressure at which the inner cylinder will be completely plastic.

Autofrettage Only

This option should be selected when the user is interested in solving a single cylinder autofrettage only problem.

Shrinkfit Only

This option should be chosen when the user is interested in solving a two cylinder, shrinkfit only problem.

Shrinkfit and Autofrettage

This option should be chosen when the user is interested in solving a two cylinder autofrettage and shrinkfit problem. The program first calculates the stress state caused by the autofrettage of the inner cylinder, and then superimposes the stresses caused by the shrinkfit of the outer cylinder and that caused by the operating pressure.

Stress

Stress With Autofrettage Pressure (Inner Cylinder)

Calculates the stress state of the inner cylinder with the autofrettage pressure applied.

Residual Stress After Autofrettage (Inner Cylinder)

Calculates the residual stress state of the inner cylinder after the autofrettage pressure is released.

Stress Due To Shrink Fit Only

Calculates the stresses in both cylinders caused by the shrinkfitting process. Does not include the residual stresses from the autofrettage process.

Total Stress After Shrink Fit

Calculates the total stress state in both cylinders after the shrinkfitting process. Includes the stresses from the autofrettage process.

Stress With Operating Pressure Only

Calculates the stresses caused by the application of the operating pressure. Does not include the residual stresses from the autofrettage process or the shrinkfitting process.

Total Stress With Operating Pressure

Calculates the total stress state in both cylinders after the application of the operating pressure. Includes stresses from the autofrettage and shrinkfitting processes.

Mesh

Set Number of nodes

The stresses in the cylinders are calculated at discrete points in the cylinders. This option allows the user to determine the number of nodes in the inner and outer cylinders. Note: The error "Out of memory" will occur if the number of nodes in the mesh is set to a large number. To correct this the application memory size will need to be increased. In order to do this, first quit the Under Pressure application. Next select the Under Pressure application by single clicking on its icon. Next select "Get Info" from the file menu. Now click the mouse in the box labeled application memory size and increase the memory allotment.

Experimentation will determine the appropriate amount of memory when running large numbers of nodes.

Appendix C

List of Symbols

σ_r	The radial stress.
σ_θ	The circumferential stress.
σ_z	The stress in the z direction.
k	The yield criteria constant.
τ	The shear stress.
r	The radius at which the stress is being calculated.
r_i	The inner radius of the inner cylinder.
r_o	The outer radius of the outer cylinder.
r_p	The depth of yielding in the inner cylinder that is caused by autofrettage pressure.
p_c	The interface pressure between the plastic and elastic zones in the inner cylinder during the autofrettage process.
u	The radial displacement of a point at radius r .
ϵ_r	The radial strain.
ϵ_θ	The circumferential strain.
ν_i	Poisson's ratio in the inner cylinder.
ν_o	Poisson's ratio in the outer cylinder.
p_i	The internal pressure.
p_o	The external pressure.
p_{auto}	The pressure used in the autofrettage process.
p_{int}	The interface pressure between the two cylinders that is caused by the shrinkfitting process.
E	Modulus of elasticity.
R_o	The outer radius of the outer cylinder.
R_i	The inner radius of the outer cylinder.

Δ	The magnitude of the shrink fit.
σ_{rr}	The residual radial stress.
σ_{tR}	The residual circumferential stress.
σ_{tA}	The residual circumferential stress at $r=r_i$ as calculated from elastic unloading.
σ_{tc}	The corrected circumferential stress at the bore.
r_z	The radius where $\sigma_t - \sigma_r = 0$.
B_f	The Bauschinger factor.
p_d	The operating pressure.

Appendix D

Source Code

```
changecursor 4          ***Change Cursor while program starts

***** find screen Limits and intilize field locations and graph size
screenh=SYSTEM(6)
screenw=SYSTEM(5)
IF (screenw<640 OR screenh<480) THEN
    GOSUB smallmac
    macsize$="small"
ELSE
    GOSUB bigmac
    macsize$="big"
END IF

WINDOW 1, "Under Pressure",(win1x1,win1y1)-(win1x2,win1y2),5
*****
** Create Menu Selections **
*****
MENU 1,0,1,"File"
MENU 1,1,1,"Save current Data":CmdKey 1,1,"S"
MENU 1,2,1, "Open Old Data":CmdKey 1,2,"O"
MENU 1,3,0,"-----"
MENU 1,4,1,"Help":CmdKey 1,4,"H"
MENU 1,5,1,"Quit":CmdKey 1,5,"Q"
MENU 2,0,1,"Edit"
MENU 2,1,1,"Copy Graph to Clipboard":CmdKey 2,1,"C"
MENU 2,2,1,"Copy Current Screen to Clipboard"
MENU 3,0,1,"Report"
MENU 3,1,1,"Print This Screen"
MENU 3,2,1,"Print Report"
MENU 3,3,1,"Write Text File of Stress Arrays"
MENU 3,4,1,"Print Tabular Form of Stress Arrays"
MENU 3,5,1,"Examine Tabular Form of Stress Arrays"
MENU 3,6,1,"Create Report file"
MENU 4,0,1,"Yield Criteria"
MENU 4,1,2,"Tresca":CmdKey 4,1,"T"
MENU 4,2,1,"Von Mises":CmdKey 4,2,"V"
MENU 5,0,1,"AutoP"
MENU 5,1,1,"User Supplies Autofrettage pressure"
MENU 5,2,2,"User Supplies Depth Of Yielding"
MENU 5,3,1,"Calculate Autofrettage Pressure"
MENU 5,4,1,"Calculate Presure at Which Yielding Begins and Ends in Inner Cylinder"
```

```

MENU 5,5,1,"-----"
MENU 5,6,1,"AutoFrettag only"
MENU 5,7,1,"Shrinkfit only"
MENU 5,8,2,"Shrinkfit and AutoFrettag"
MENU 6,0,1,"Stress"
MENU 6,1,1,"Stress With Autofrettag pressure(Inner Cylinder)"
MENU 6,2,1,"Residual Stress After Autofrettag(Inner Cylinder)"
MENU 6,3,0,"-----"
MENU 6,4,0,"Stress due to Shrink Fit Only"
MENU 6,5,0,"Total Stress After Shrink Fit"
MENU 6,6,0,"-----"
MENU 6,7,0,"Stress From Operating Pressure Only"
MENU 6,8,0,"Total Stress With Operating Pressure"
MENU 7,0,1,"Mesh"
MENU 7,1,1,"Set Number Of Nodes In Cylinder Mesh":CmdKey 7,1,"M"
MENU 8,0,1,"Units"
MENU 8,1,2,"English"
MENU 8,2,1,"SI"

```

```

*****
** sets up for multiple tones at same time **
*****

```

```

WAVE 0,SIN
WAVE 1,SIN
WAVE 2,SIN
WAVE 3,SIN

```

```

*****
** initializes variables , flags fields ect **
*****

```

```

lasttime=TIMER          ** used in animated cursor
refreshflag=0           ** screen refresh
Innerness=19            ** mesh for inner cylinder
innernessplus=Innerness+1 ** mesh for inner cylinder
Outerness=19            ** mesh for outer cylinder
outernessplus=Outerness+1 ** mesh for outer cylinder
CH=.5                   ** strain harding constant for
depthorpres=2           ** flag for determining if user
withPresFlag=0          **
errorflag=0             ** after displaying error message
currentyeildcrit$="Tresca" ** set yield criteria to Tresca
problemtyp$="Both"      ** set problemtyp to autofrettag
printscreenerrorflag=0  **
curnum%=128             ** set first cursor number for
IF macsize$="small" THEN
    yoriginlocation=226  *** Set origin of graphs for on screen
ELSE
    yoriginlocation=320

```

```

END IF
  GOSUB SetGraphLocation      *** set graph locations
  cleargraphflag=0           **** dont overwrite report graphs
  graphtitleflag=0           *** move graph title up for report
  LengthUnit$=" in"          *** units for reports and graphs
  PresUnit$=" psi"
  writefileflag=0
  arraytextfile=0
  firsttime=0

' *****
**Assign memory locations for scroll bars and pictures **
' *****

DIM scr%(3),bar%(3),s&,R%(3)
DIM top%,max%,linenum%,gap%
DIM Graphpict%(4500)

GOSUB UserInterface1 *** set up text fields for data entry
GOSUB dimension

' *****
** sets up edit field cursor placement **
' *****

n=0
EDIT FIELD n+1

' *****
** Main Program Loop **
** LOOKS FOR ACTION in Fields and Menus **
' *****

CALL INITCURSOR
ON MENU GOSUB Menucheck: MENU ON
ON TIMER(1/3) GOSUB cursor
control1:
  errorflag=0
  LET action=DIALOG(0)
  IF action=5 THEN GOSUB refresh
  IF action=7 OR 2 THEN GOSUB fld
  GOSUB boxinScreen
GOTO control1
' *****

' *****
** Draw Animated pressure cursor **
' *****

cursor:
change cursor curnum%
curnum%=curnum%+1
IF curnum%=132 THEN curnum%=128
RETURN

```

```

' *****
** Controls cursor placement in FIELDS      **
' *****

```

```
fld:
```

```
IF action=7 THEN n=n+1 : EDIT FIELD 1+n MOD 11
```

```
IF action=2 THEN n=DIALOG(2)-1
```

```
RETURN
```

```

' *****
** define all arrays                        **
' *****

```

```
dimension:
```

```
DIM sigma(3,innermeshplus)
```

```
DIM Unsigma(3,innermeshplus)
```

```
DIM Ressigma(3,innermeshplus)
```

```
DIM shrksigma(3,innermeshplus)
```

```
DIM Resshrksigma(3,innermeshplus)
```

```
DIM jshrksigma(3,outermeshplus)
```

```
maxmesh=innermeshplus
```

```
IF outermeshplus > innermeshplus THEN maxmesh=outermeshplus
```

```
DIM x(maxmesh),y(maxmesh),Q(maxmesh),R(maxmesh)
```

```
DIM plasticCriteria(2,maxmesh)
```

```
DIM plasticCriteria2i(2,maxmesh)
```

```
DIM plasticCriteria2j(2,maxmesh)
```

```
DIM designsigma(3,innermeshplus)
```

```
DIM jdesignsigma(3,outermeshplus)
```

```
DIM Resdesignsigma(3,innermeshplus)
```

```
DIM jResdesignsigma(3,outermeshplus)
```

```
RETURN
```

```

' *****
** Calculating loading stresses for Autofrettage
** sigma(location of r, value of radial stress, val of theta stress)
' *****

```

```
stresscalc:
```

```
IF currentyeildcrit$="Tresca" THEN TwiceTau=Mat
```

```
IF currentyeildcrit$="von Mises" THEN TwiceTau=(2/(3^(1/2)))*Mat
```

```
deltar=(RO-Ri)/Innermesh ** calculate node size
```

```
R=Ri
```

```
i=0
```

```
*** Calculate stresses in Plastic zone
```

```
TIMER ON
```

```
*** timer for animated cursor
```

```
WHILE R <= dep
```

```
i=i+1
```

```
sigma(1,i)=R
```

```
sigma(2,i)=TwiceTau*LOG(R)-AutoP-(TwiceTau*LOG(Ri))
```

```

        sigma(3,i)=((TwiceTau) +sigma(2,i))
        R=R+deltar
    WEND
    PlasElasIntfPres=-1*(sigma(2,i))      '**** calculate plastic elastic interface pressure
    RIP=R-deltar                          '**** RIP is the depth of plastic yielding to the closest interval
    elasticstart=i+1
    ' *** Calculate stresses in ELASTIC ZONE for Autofrettage
    FOR i=(elasticstart) TO (innermeshplus)
        sigma(1,i)=R
        sigma(2,i)=(((PlasElasIntfPres)*RIP^2)/(RO^2-RIP^2))*(1-((RO^2)/(R^2)))
        sigma(3,i)=(((PlasElasIntfPres)*RIP^2)/(RO^2-RIP^2))*(1+((RO^2)/(R^2)))
        R=R+deltar
    NEXT i
    refreshflag=1
    IF withPresFlag=1 THEN GOSUB graphwithpres
    TIMER OFF      '****turn off animated cursor
    IF withPresFlag=1 THEN withPresFlag=0 :RETURN

' *****
** UNLOAD BY APPLYING NEGATIVE AUTO PRESSURE      *
** Calculate Stresses caused by negative Autofrettage pressure
' *****
    GOSUB findmaxwithautop      '*** find max stress with pressure      for report
    TIMER ON
    GOSUB enablestressmenus
    IF problemtype$ = "Autofrettage only" THEN GOSUB      enablestressmenus2
    R=Ri
    FOR i=1 TO innermeshplus
        Unsigma(1,i)=R
        Unsigma(2,i)= -1*(((AutoP)*Ri^2)/(RO^2-Ri^2))*(1-((RO^2)/(R^2)))
        Unsigma(3,i)= -1*(((AutoP)*Ri^2)/(RO^2-Ri^2))*(1+((RO^2)/(R^2)))
        R=R+deltar
    NEXT i

' *****
*** FIND RESIDUAL STRESS AFTER UNLOADING      *****
' *****
    i=0
    FOR i=1 TO innermeshplus
        Ressigma(1,i)=Unsigma(1,i)
        Ressigma(2,i)=Unsigma(2,i)+sigma(2,i)
        Ressigma(3,i)=Unsigma(3,i)+sigma(3,i)
    NEXT i

    '*****
    ** check to see bausinger criteria is met ***
    '*****

    BashCriteria=Ressigma(3,1)
    goesplasticUnload=0
    IF ((BashCriteria)<((-1)*(4)*TwiceTau))THEN      goesplasticUnload=1

```

```

      IF (goesplasticUnload=1 AND problemtype$="Autofrettage only") THEN GOSUB
RecalcResStress
      IF (goesplasticUnload<>1 AND problemtype$ = "Autofrettage only" OR (problemtype$
<>"Autofrettage only") THEN
      EDIT FIELD 56,"Linear Equations Used For Calculating Unloading Stresses in Inner
Cylinder",(ef56x1,ef56y1)-(ef56x2,ef56y2),3,1
      mrt$=""
      EDIT FIELD 57,mrt$,(ef57x1,ef57y1)-(ef57x2,ef57y2),3,1
      resbore=Ressigma(3,1)
END IF
      IF problemtype$ = "Autofrettage only" THEN
      Pd=((TwiceTau-resbore)*(RO^2-Ri^2))/(2*(RO^2))
      Reyielding$=STR$(Pd)
      Reyielding$=LEFT$(Reyielding$,9)
      EDIT FIELD 128,Reyielding$ ,(ef128x1,ef128y1)-(ef128x2,ef128y2),2,2
      Factor$=" "
      EDIT FIELD 129,Factor$,(ef129x1,ef129y1)-(ef129x2,ef129y2),3,2
END IF
      refreshflag=2
      GOSUB resautograph
      TIMER OFF
      RETURN

```

```

*****
** if bausinger criteria is met, then recalculate residual stress for auto frettage
*****
RecalcResStress:
***** Get corected tangential bore stress
sigmacorrected=(TwiceTau)*((- .4)+(CH*(((Ressigma(3,1))/(TwiceTau))+.4)))
IF ((sigmacorrected/TwiceTau) < -.7) THEN sigmacorrected=(- .7*TwiceTau)
resbore=sigmacorrected
***** Find RZ (RZ is the depth of reyielding)
RZ=Ri
mindifference=Ressigma(3,1)-Ressigma(2,1)
i=1
R=Ri+deltar
WHILE R <= dep
  i=i+1
  difference=Ressigma(3,i)-Ressigma(2,i)
  IF (ABS(difference))<(ABS(mindifference)) THEN
    mindifference=difference
    RZ=Ressigma(1,i)
  END IF
  R=R+deltar
WEND
RZ$=STR$(RZ)
RZ$=LEFT$(RZ$,5)
SPAC$="Depth Through Which the Bauschinger Correction is Applied="
mrt$=SPAC$+RZ$
EDIT FIELD 57,mrt$,(ef57x1,ef57y1)-(ef57x2,ef57y2),3,1

```

```

    baus$ = "Stresses Corrected for the Bauschinger Effect,      Correction Factor="
    bausnum$=STR$(sigmacorrected/ TwiceTau)
    bausnum$=LEFT$(bausnum$,4)      **** bausnum is the bausinger      'correction
factor
    bausnum2$=baus$+bausnum$
    EDIT FIELD 56,bausnum2$,(ef56x1,ef56y1)-(ef56x2,ef56y2),3,1

    i=0
    R=Ri
    WHILE R <= RZ
        i=i+1
        PreCorrectionRadial=Ressigma(2,i)
        Ressigma(1,i)=R
        Ressigma(2,i)=sigmacorrected*((RZ*LOG(R/Ri)+Ri-R)/(RZ-Ri))
        Ressigma(3,i)=sigmacorrected*((RZ*(LOG(R/Ri)+1)+Ri- (2*R))/(RZ-Ri))
        R=R+deltar
    WEND
    correctionfactor=Ressigma(2,i)/PreCorrectionRadial
    ***** correct radial And Tangential stresses
    elascorrectstart=i+1
    FOR i=elascorrectstart TO innermeshplus
        Ressigma(1,i)=R
        Ressigma(2,i)=correctionfactor*Ressigma(2,i)
        Ressigma(3,i)=correctionfactor*Ressigma(3,i)
        R=R+deltar
    NEXT i
    RETURN

' *****
** Loads arrays for no residual stress      **
' *****

nostress:
TIMER ON
refreshflag=0
GOSUB getData0
IF errorflag=1 THEN TIMER OFF:RETURN
    GOSUB yieldprop
    GOSUB enablestressmenus0
    GOSUB enablestressmenus
    AutoP=0
    dep=0
    AutoP$=STR$(AutoP)
    AutoP$=LEFT$(AutoP$,10)
    dep$=STR$(dep)
    dep$=LEFT$(dep$,10)
    EDIT FIELD CLOSE 4
    EDIT FIELD CLOSE 5
    EDIT FIELD 4,AutoP$,(ef4x1,ef4y1)-(ef4x2,ef4y2),2,2
    EDIT FIELD 5,dep$,(ef5x1,ef5y1)-(ef5x2,ef5y2),1,2

IF currentycildcrit$="Tresca" THEN TwiceTau=Mat

```

```
IF currentyeildcrit$="von Mises" THEN TwiceTau=(2/(3^(1/2)))*Mat
```

```
    deltar=(RO-Ri)/Innermesh
```

```
    R=Ri
```

```
    i=0
```

```
    FOR i=1 TO innermeshplus
```

```
        sigma(1,i)=R
```

```
        sigma(2,i)=0
```

```
        sigma(3,i)=0
```

```
        Rsigma(1,i)=sigma(1,i)
```

```
        Rsigma(2,i)=0
```

```
        Rsigma(3,i)=0
```

```
    R=R+deltar
```

```
    NEXT i
```

```
GOSUB clearGraph
```

```
TIMER OFF
```

```
RETURN
```

```
'*****
```

```
'*****
```

```
'** Clears arrays for new problem **
```

```
'*****
```

```
cleararrays:
```

```
    FOR i=1 TO innermeshplus
```

```
        sigma(1,i)=0
```

```
        sigma(2,i)=0
```

```
        sigma(3,i)=0
```

```
        Rsigma(1,i)=0
```

```
        Rsigma(2,i)=0
```

```
        Rsigma(3,i)=0
```

```
        Unsigma(1,i)=0
```

```
        Unsigma(2,i)=0
```

```
        Unsigma(3,i)=0
```

```
        Reshrksigma(1,i)=0
```

```
        Reshrksigma(2,i)=0
```

```
        Reshrksigma(3,i)=0
```

```
        shrksigma(1,i)=0
```

```
        shrksigma(2,i)=0
```

```
        shrksigma(3,i)=0
```

```
        designsigma(1,i)=0
```

```
        designsigma(2,i)=0
```

```
        designsigma(3,i)=0
```

```
        Resdesignsigma(1,i)=0
```

```
        Resdesignsigma(2,i)=0
```

```
        Resdesignsigma(3,i)=0
```

```
    NEXT i
```

```
    FOR i=1 TO outermeshplus
```

```
        jshrksigma(1,i)=0
```

```
        jshrksigma(2,i)=0
```

```
        jshrksigma(3,i)=0
```

```
        jdesignsigma(1,i)=0
```

```

jdesignsigma(2,i)=0
jdesignsigma(3,i)=0
jResdesignsigma(1,i)=0
jResdesignsigma(2,i)=0
jResdesignsigma(3,i)=0
NEXT i
RETURN

'*****
** Draw lines for graphing and labels graph with fields **
'*****

coordinatesystem:
  GOSUB clearGraph
  CALL TEXTSIZE(9)
  CALL TEXTFACE(0)
  EDIT FIELD 33,"Stress",(ef33x1,ef33y1)-(ef33x2,ef33y2),3,2
  EDIT FIELD 44,PresUnit$,(ef33x1,(ef33y2-3))- (ef33x2,(ef33y2+10)),3,2
  EDIT FIELD 34,"Stress",(ef34x1,ef34y1)-(ef34x2,ef34y2),3,2
  EDIT FIELD 45,PresUnit$,(ef34x1,(ef34y2-3))- (ef34x2,(ef34y2+10)),3,2
  EDIT FIELD 35,"RI",(ef35x1,ef35y1)-(ef35x2,ef35y2),3,2
  EDIT FIELD 36,"RI",(ef36x1,ef36y1)-(ef36x2,ef36y2),3,2
  EDIT FIELD 37,"RO",(ef37x1,ef37y1)-(ef37x2,ef37y2),3,2
  EDIT FIELD 46,LengthUnit$,(ef37x1-4),(ef37y2-2))- (ef37x2,(ef37y2+11)),3,2
  EDIT FIELD 38,"RO",(ef38x1,ef38y1)-(ef38x2,ef38y2),3,2
  EDIT FIELD 47,LengthUnit$,(ef38x1-4),(ef38y2-2))- (ef38x2,(ef38y2+11)),3,2
  CALL TEXTFACE(1)
  EDIT FIELD 30,"Radial Stress",(ef39x1,ef30y1)- (ef30x2,ef30y2),3,2
  EDIT FIELD 31,"Hoop Stress",(ef31x1,ef31y1)-(ef31x2,ef31y2),7,2
  LINE(axes1x1,axes1y1)-(axes1x2,axes1y2)
  LINE(axes2x1,axes2y1)-(axes2x2,axes2y2)
  LINE(axes3x1,axes3y1)-(axes3x2,axes3y2)
  LINE(axes4x1,axes4y1)-(axes4x2,axes4y2)
  CALL TEXTFACE(0)
  CALL TEXTSIZE(12)
RETURN

coordinatesystem2:
  GOSUB clearGraph
  CALL TEXTSIZE(9)
  EDIT FIELD 44,PresUnit$,(ef33x1,(ef33y2-3))- (ef33x2,(ef33y2+10)),3,2
  EDIT FIELD 45,PresUnit$,(ef34x1,(ef34y2-3))- (ef34x2,(ef34y2+10)),3,2
  EDIT FIELD 46,LengthUnit$,(ef37x1-1),(ef37y2-2))-
  ((ef37x2+3),(ef37y2+11)),3,2
  EDIT FIELD 47,LengthUnit$,(ef38x1-1),(ef38y2-2))-
  ((ef38x2+3),(ef38y2+11)),3,2
  EDIT FIELD 133,"Stress",(ef33x1,ef33y1)-(ef33x2,ef33y2),3,2
  EDIT FIELD 134,"Stress",(ef34x1,ef34y1)-(ef34x2,ef34y2),3,2
  EDIT FIELD 135,"RI",(ef35x1,ef35y1)-(ef35x2,ef35y2),3,2
  EDIT FIELD 136,"RI",(ef36x1,ef36y1)-(ef36x2,ef36y2),3,2
  EDIT FIELD 137,"ORO",(ef137x1,ef137y1)-(ef137x2,ef137y2),3,2

```

```

EDIT FIELD 138,"ORO",(ef138x1,ef138y1)-(ef138x2,ef138y2),3,2
CALL TEXTFACE(1)
EDIT FIELD 130,"Radial Stress",(ef39x1,ef30y1)- (ef30x2,ef30y2),3,2
EDIT FIELD 131,"Hoop Stress",(ef31x1,ef31y1)- (ef31x2,ef31y2),7,2
  LINE(axes1x1,axes1y1)-(axes1x2,axes1y2)
  LINE(axes2x1,axes2y1)-(axes2x2,axes2y2)
  LINE(axes3x1,axes3y1)-(axes3x2,axes3y2)
  LINE(axes4x1,axes4y1)-(axes4x2,axes4y2)
CALL TEXTFACE(0)
CALL TEXTSIZE(12)
RETURN

```

```

' *****
** Calculate interface pressure between **
** cylinders caused by shrinkfit **
' *****

interface:
GOSUB getdata2
IF errorflag=1 THEN RETURN
IF currentyeildcrit$="Tresca" THEN TwiceTau=Mat
IF currentyeildcrit$="von Mises" THEN TwiceTau=(2/(3^(1/2)))*Mat
IF currentyeildcrit$="Tresca" THEN TwiceTauO=OMat
IF currentyeildcrit$="von Mises" THEN TwiceTauO=(2/(3^(1/2)))*OMat

** eq for interface pres with diff e's
DELTASHRINK=(RO-ORI)
Ipr1=(RO/(OMat*DELTASHRINK))
Ipr2=(RO/(Mat*DELTASHRINK))
Ipr3=(RO^2/(ORO^2-RO^2))*(1+(ORO^2/RO^2))+Oposs
Ipr4=(RO^2/(RO^2-Ri^2))*(1+(Ri^2/RO^2))-poss
ipint=Ipr1*Ipr3+Ipr2*Ipr4
Ipress=1/ipint
  Ipress$=STR$(Ipress)
  Ipres$=LEFT$(Ipress$,10)
EDIT FIELD 205,Ipres$, (ef205x1,ef205y1)-(ef205x2,ef205y2),2,2
RETURN

```

```

' *****
*** FIND STRESS DUE TO SHRINK FIT ONLY *****
' *****

shrinkpres:
GOSUB interface *** to find interface pressure
IF errorflag=1 THEN RETURN
  deltar=(RO-Ri)/Innermesh
  deltar2=(ORO-RO)/Outermesh
  R1=Ri
  R2=RO

  FOR i=1 TO innermeshplus

```

```

    shrksigma(1,i)=R1
    Rssigma(1,i)=R1
    shrksigma(2,i)=((Ipress*RO^2)/(RO^2-Ri^2))*(((Ri/R1)^2)-1)
    shrksigma(3,i)=(-1)*((Ipress*RO^2)/(RO^2-Ri^2))*(((Ri/R1)^2)+1)
    R1=R1+deltar
NEXT i
FOR j=1 TO outermeshplus
    jshrksigma(1,j)=R2
    jshrksigma(2,j)=((Ipress*RO^2)/(ORO^2-RO^2))*(1- ((ORO/R2)^2))
    jshrksigma(3,j)=((Ipress*RO^2)/(ORO^2-RO^2))*(1+((ORO/R2)^2))
    R2=R2+deltar2
NEXT j

***** check to see if the outer cylinder goes plastic
from the shrink fit
goesplasticshrink=0
shrinkplasdepthj=0
FOR i=1 TO outermeshplus
    plasticCriteria2j(1,i)=jshrksigma(1,i)
    plasticCriteria2j(2,i)=jshrksigma(3,i)-jshrksigma(2,i)
    IF ABS(plasticCriteria2j(2,i))>(TwiceTauO) THEN
        shrinkplasdepthj=plasticCriteria2j(1,i):goesplasticshrink=1
NEXT i
IF goesplasticshrink=1 THEN
    i=0
    R=RO

***** recalculate the plastic zone stresses using ther plastic formulas
WHILE R <= shrinkplasdepthj
    i=i+1
    jshrksigma(1,i)=R ***** CHECK THESE EQUATIONS!!!!!!!
    jshrksigma(2,i)=(TwiceTauO*LOG(R))-Ipress-
    (TwiceTauO*LOG(Ri))
    jshrksigma(3,i)=((TwiceTau) +shrksigma(2,i))
    R=R+deltar2
WEND
SOUND 625,2,2
SOUND 630,2,2
SOUND 635,2,2
SOUND 640,2,2
SOUND 645,2,2
SOUND 650,2,2
SOUND 645,2,2
SOUND 640,2,2
SOUND 635,2,2
SOUND 630,2,2
SOUND 625,2,2
SOUND 620,2,2
GOSUB plasticshrinkerror *****display warning window
END IF
refreshflag=3

```

```

        IF (Resshrinkflag=1) THEN Resshrinkflag=0: GOTO shrinkskip
GOSUB shrinkprnt
RETURN
*****

*****

*** FIND RESIDUAL STRESS AFTER SHRINK FIT *****
*****

shrinkskip:
refreshflag=4
GOSUB enablestressmenus2:
    FOR i=1 TO innermeshplus
        Resshrksigma(1,i)=Ressigma(1,i)
        Resshrksigma(2,i)=Ressigma(2,i)+shrksigma(2,i)
        Resshrksigma(3,i)=Ressigma(3,i)+shrksigma(3,i)
    NEXT i
        *****
        *** check to see if Bausinger criteria is met ***
        *****
        BashCriteria=Resshrksigma(3,1)
        goesplasticUnload=0
        IF ((BashCriteria)<((-1)*(4)*TwiceTau))THEN goesplasticUnload=1
        IF (goesplasticUnload=1) THEN GOSUB RecalcResShrkStress
        IF (goesplasticUnload<>1)THEN
            IF problemtype$="Shrinkfit only" THEN
                EDIT FIELD 56,"",(ef56x1,ef56y1)-(ef56x2,ef56y2),3,1
            ELSE
                EDIT FIELD 56,"Linear Equations Used For Calculating Unloading
                Stresses in Inner Cylinder",(ef56x1,ef56y1)-(ef56x2,ef56y2),3,1
            END IF
            mrt$=""
            EDIT FIELD 57,mrt$,(ef57x1,ef57y1)-(ef57x2,ef57y2),3,1
            resbore=Resshrksigma(3,1)
        END IF
        ***** calculate reyielding pressure
        Pd=((TwiceTau-resbore)*(RO^2-Ri^2))/(2*(RO^2))
        Relyielding$=STR$(Pd)
        Relyielding$=LEFT$(Relyielding$,9)
        EDIT FIELD 128,Relyielding$ ,(ef128x1,ef128y1)- (ef128x2,ef128y2),2,2
        Factor$=" "
        EDIT FIELD 129,Factor$,(ef129x1,ef129y1)- (ef129x2,ef129y2),3,2

GOSUB resshrinkprnt

RETURN

*****

** Recalculate Residual Stress after the shrink ***
** fit if the cylinder goes plastic on shrinkfit ***
*****

RecalcResShrkStress:

```

```

'WINDOW 5, "Hey Now", (40,40)-(100,100)
'PRINT ""
'INPUT a$
'WINDOW CLOSE 5
  ***** Get corected tangential bore stress
  sigmacorrected=(TwiceTau)*((- .4)+(CH*(((Resshrksigma(3,1))/(TwiceTau))+.4)))
  IF ((sigmacorrected/TwiceTau) < -.7) THEN sigmacorrected=(- .7*TwiceTau)
  resbore=sigmacorrected
  ***** Find RZ
  RZ=Ri
  mindifference=Resshrksigma(3,1)-Resshrksigma(2,1)
  i=1
  R=Ri+deltar
  WHILE R <= dep
    i=i+1
    difference=Resshrksigma(3,i)-Resshrksigma(2,i)
    IF (ABS(difference))<(ABS(mindifference)) THEN
      mindifference=difference
      RZ=Resshrksigma(1,i)
    END IF
    R=R+deltar
  WEND
  RZ$=STR$(RZ)
  RZ$=LEFT$(RZ$,5)
  SPAC$="Depth Through Which the Bauschinger Correction is      Applied="
  mrt$=SPAC$+RZ$
  EDIT FIELD 57,mrt$(ef57x1,ef57y1)-(ef57x2,ef57y2),3,1
  baus$ = "Stresses Corrected for the Bauschinger Effect,      Correction Factor="
  bausnum$=STR$(sigmacorrected/TwiceTau)
  bausnum$=LEFT$(bausnum$,4)
  bausnum2$=baus$+bausnum$
  EDIT FIELD 56,bausnum2$(ef56x1,ef56y1)-(ef56x2,ef56y2),3,1

  i=0
  R=Ri
  WHILE R <= RZ
    i=i+1
    PreCorrectionRadial=Resshrksigma(2,i)
    Resshrksigma(1,i)=R
    Resshrksigma(2,i)=sigmacorrected*((RZ*LOG(R/Ri)+Ri-R)/(RZ- Ri))
    Resshrksigma(3,i)=sigmacorrected*((RZ*(LOG(R/Ri)+1)+Ri- (2*R))/(RZ-Ri))
    R=R+deltar
  WEND
  correctionfactor=Resshrksigma(2,i)/PreCorrectionRadial
  ***** correct radial And Tangential stresses
  cstart=i+1
  FOR i=cstart TO innermeshplus
    Resshrksigma(1,i)=R
    Resshrksigma(2,i)=correctionfactor*Resshrksigma(2,i)
    Resshrksigma(3,i)=correctionfactor*Resshrksigma(3,i)
    R=R+deltar
  
```

```

NEXT i
R2=RO
FOR i=1 TO outermeshplus
    jshrksigma(1,i)=R2
    jshrksigma(2,i)=correctionfactor*jshrksigma(2,i)
    jshrksigma(3,i)=correctionfactor*jshrksigma(3,i)
    R2=R2+deltar2
NEXT i

'***** end of bauss correction for shrink
RETURN

'*****
** calculate stress due to design pressure only **
'*****
firstdesprescalc:
IF problemtype$<>"Autofrettage only" THEN GOSUB getdata2
IF errorflag=1 THEN RETURN
GOSUB getdata3

    deltar=(RO-Ri)/Innermesh
    deltar2=(ORO-RO)/Outermesh
    R1=Ri
    R2=RO
    orot=ORO
    IF problemtype$="Autofrettage only" THEN orot=RO
    FOR i = 1 TO innermeshplus
        designsigma(1,i)=R1
        designsigma(2,i)=((designpress*(Ri^2))/(orot^2-Ri^2))*(1- ((orot^2)/(R1^2)))
        designsigma(3,i)=((designpress*(Ri^2))/(orot^2- Ri^2))*(1+((orot^2)/(R1^2)))
        R1=R1+deltar
    NEXT i
    IF problemtype$<>"Autofrettage only" THEN
        FOR j=1 TO outermeshplus
            jdesignsigma(1,j)=R2
            jdesignsigma(2,j)=((designpress*(Ri^2))/(orot^2-Ri^2))*(1- ((orot^2)/(R2^2)))
            jdesignsigma(3,j)=((designpress*(Ri^2))/(orot^2- Ri^2))*(1+((orot^2)/(R2^2)))
            R2=R2+deltar2
        NEXT j
    END IF
    IF problemtype$="Autofrettage only" THEN
        IF dep<>0 THEN
            totalyield=(- 1*resborc*(LOG(dep/Ri)))+(TwiceTau*(LOG(RO/dep)))
            Factor=totalyield/designpress
        ELSE
            Factor=yieldfin/designpress
        END IF
        Factor$=STR$(Factor)
        Factor$=LEFT$(Factor$,5)
        EDIT FIELD 129,Factor$, (ef129x1,ef129y1)- (ef129x2,ef129y2),2,2

```

```

END IF
IF problemtype$ <> "Autofrettage only" THEN
  IF problemtype$ = "Both" THEN
    totalyield = (-
      1 * resbore * (LOG(dep/Ri)) + (TwiceTau * (LOG(RO/dep))) + (Twice
      auO * (LOG(ORO/RO)))
    )
  END IF
  IF problemtype$ = "Shrinkfit only" THEN
    totalyield = (TwiceTau * (LOG(RO/Ri))) + (TwiceTauO * (LOG(ORO/R
    )))
  END IF
  Factor = totalyield / designpress
  Factor$ = STR$(Factor)
  Factor$ = LEFT$(Factor$, 5)
  EDIT FIELD 129, Factor$, (ef129x1, ef129y1) - (ef129x2, ef129y2), 2, 2
END IF

refreshflag = 5
IF (resdesignflag = 1) THEN resdesignflag = 0: GOTO DESIGNskip
IF problemtype$ <> "Autofrettage only" THEN
  GOSUB designPrnt
ELSE
  GOSUB designAutoPrnt
END IF
RETURN

' *****
' *** FIND total STRESS with DESIGN PRESSURE **
' *****
DESIGNskip:
refreshflag = 6
IF problemtype$ = "Autofrettage only" THEN
  FOR i = 1 TO innermeshplus
    Resdesignsigma(1,i) = Ressigma(1,i)
    Resdesignsigma(2,i) = Ressigma(2,i) + designsigma(2,i)
    Resdesignsigma(3,i) = Ressigma(3,i) + designsigma(3,i)
  NEXT i
ELSE
  FOR i = 1 TO innermeshplus
    Resdesignsigma(1,i) = Resshrksigma(1,i)
    Resdesignsigma(2,i) = Resshrksigma(2,i) + designsigma(2,i)
    Resdesignsigma(3,i) = Resshrksigma(3,i) + designsigma(3,i)
  NEXT i
  FOR i = 1 TO outermeshplus
    jResdesignsigma(1,i) = jshrksigma(1,i)
    jResdesignsigma(2,i) = jshrksigma(2,i) + jdesignsigma(2,i)
    jResdesignsigma(3,i) = jshrksigma(3,i) + jdesignsigma(3,i)
  NEXT i
END IF

' *****
' ** check to see if it goes plastic with design pressure **
' *****

```

```

    goesplasticdes=0
    desplasdepthi=0
    desplasdepthj=0
    FOR i=1 TO innermeshplus
        plasticCriteria2i(1,i)=Resdesignsigma(1,i)
        plasticCriteria2i(2,i)=Resdesignsigma(3,i)-Resdesignsigma(2,i)
        IF ABS(plasticCriteria2i(2,i))>(TwiceTau) THEN
desplasdepthi=plasticCriteria2i(1,i):goesplasticdes=1
    NEXT i
    IF problemtype$<>"Autofrettage only"THEN
        FOR i=1 TO outermeshplus
            plasticCriteria2j(1,i)=jResdesignsigma(1,i)
            plasticCriteria2j(2,i)=jResdesignsigma(3,i)- jResdesignsigma(2,i)
            IF ABS(plasticCriteria2j(2,i))>(TwiceTauO) THEN
desplasdepthj=plasticCriteria2j(1,i):goesplasticdes=1
        NEXT i
    END IF
    IF goesplasticdes=1 THEN GOSUB designwarning
        IF problemtype$="Autofrettage only"THEN
            GOSUB AresdesignPrnt
        ELSE
            GOSUB resdesignPrnt
        END IF
    RETURN

'*****
'** displays message for plactic action during operating pressure**
'*****

    designwarning:
        WINDOW 6," ",(90,65)-(370,160),2
        CALL TEXTFACE(1)
        EDIT FIELD 103,"Warning! Plastic action occured during",(1,20)- (285,35),7,2
        EDIT FIELD 104,"application of operating pressure",(10,38)- (280,53),7,2
        CALL TEXTFACE(0)
        SOUND 220,7,,0
        SOUND 293.5,7,,1
        SOUND 440,7,,2
        SOUND 587,7,,3
        BUTTON 4 ,1,"OK",(190,55)-(240,75),1
        TIMER OFF
        CALL INITCURSOR
    loop6:
    LET retkey=DIALOG(0)
    IF retkey=1 OR retkey=6 THEN GOTO getonwithit6
    GOTO loop6
    getonwithit6:
        WINDOW CLOSE 6
        GOSUB boxinScreen
    RETURN

```

```

*****
** displays error message for inappropriate input **
*****

errortrap:
    dontdoit=TIMER-dontdotwice
    IF dontdoit<10 THEN RETURN
    erfl=1
    errorflag=1
    WINDOW 5," ",(90,65)-(370,160),2
    CALL TEXTFACE(1)
    EDIT FIELD 102,"Improper Input Value",(20,20)-(250,35),7,2
    CALL TEXTFACE(0)
    SOUND 220,7,,0
    SOUND 293.5,7,,1
    SOUND 440,7,,2
    SOUND 587,7,,3
    BUTTON 2 ,1,"OK",(190,55)-(240,75),1
    TIMER OFF
    CALL INITCURSOR
loop2:
    LET retkey=DIALOG(0)
    IF retkey=1 OR retkey=6 THEN GOTO getonwithit2
    GOTO loop2
getonwithit2:
    WINDOW CLOSE 5
    GOSUB boxinScreen
    dontdotwice=TIMER
    RETURN
*****

*****
** displays error message for inappropriate filetype**
*****

fileerror:
    WINDOW 6," ",(90,65)-(370,160),2
    CALL TEXTFACE(1)
    EDIT FIELD 103,"Improper File Type",(20,20)-(250,35),7,2
    CALL TEXTFACE(0)
    SOUND 220,7,,0
    SOUND 293.5,7,,1
    SOUND 440,7,,2
    SOUND 587,7,,3
    BUTTON 4 ,1,"OK",(190,55)-(240,75),1
    TIMER OFF
    CALL INITCURSOR
loop4:
    LET retkey=DIALOG(0)
    IF retkey=1 OR retkey=6 THEN GOTO getonwithit4
    GOTO loop4
getonwithit4:
    WINDOW CLOSE 6

```

```

GOSUB boxinScreen
RETURN
'*****

'*****
** displays message for plactic action during shrinkfit**
'*****

plasticshrinkerror:
    WINDOW 6," ",(90,65)-(370,160),2
    CALL TEXTFACE(1)
    EDIT FIELD 103,"Warning! Plastic action ocured during      shrinkfit",(20,20)-
(250,35),7,2
    EDIT FIELD 104,"during shrinkfit",(20,38)-(250,53),7,2
    CALL TEXTFACE(0)
    SOUND 220,7,,0
    SOUND 293.5,7,,1
    SOUND 440,7,,2
    SOUND 587,7,,3
    BUTTON 4 ,1,"OK",(190,55)-(240,75),1
    TIMER OFF
    CALL INTCURSOR
loop5:
    LET retkey=DIALOG(0)
    IF retkey=1 OR retkey=6 THEN GOTO getonwithit5
    GOTO loop5
getonwithit5:
    WINDOW CLOSE 6
    GOSUB boxinScreen
    RETURN
'*****

'*****
** displays message for using depth of yielding = 0      **
** when problem type not set to autofrettage only      **
'*****

depZeroError:
    refreshflag=0
    WINDOW 6," ",(90,65)-(370,165),2
    CALL TEXTFACE(1)
    EDIT FIELD 103,"Problem type must be set to",(20,20)-
(250,35),7,2
    EDIT FIELD 104,"Autofrettage Only before
Depth",(20,38)-(250,53),7,2
    EDIT FIELD 105,"of Yielding may be set to
zero.",(20,56)-(250,71),7,2
    CALL TEXTFACE(0)
    SOUND 220,7,,0
    SOUND 293.5,7,,1
    SOUND 440,7,,2
    SOUND 587,7,,3
    BUTTON 4 ,1,"OK",(190,80)-(240,95),1
    TIMER OFF

```

```

CALL INTCURSOR
lop5:
    LET retkey=DIALOG(0)
    IF retkey=1 OR retkey=6 THEN GOTO geton5
GOTO lop5
geton5:
WINDOW CLOSE 6
RETURN

```

```

'*****
** Check if input data has been changed      **
'*****
datacheck:
    datachangedredo=0
    dataIsDifferent=0
    OldRi=Ri
    OldRO=RO
    OldMat=Mat
    Olddep=dep
    OldautoP=AutoP
    OldORI=ORI
    OldORO=ORO
    OldOMat=OMat
    Oldposs=poss
    OldOposs=Oposs
    Olddesignpress=designpress
    IF menuitem=1 THEN RETURN
    IF menuitem=2 THEN RETURN
    IF menuitem=5 AND problemtype$="Shrinkfit only" THEN RETURN
    Ri$=EDITS(1)
    RO$=EDITS(2)
    Mat$=EDITS(3)
    dep$=EDITS(5)
    AutoP$=EDITS(4)
    ORI$=EDITS(6)
    ORO$=EDITS(7)
    OMat$=EDITS(8)
    poss$=EDITS(9)
    Oposs$=EDITS(10)
    designpress$=EDITS(11)
    Ri=VAL(Ri$)
    RO=VAL(RO$)
    Mat=VAL(Mat$)
    dep=VAL(dep$)
    AutoP=VAL(AutoP$)
    ORI=VAL(ORI$)
    ORO=VAL(ORO$)
    OMat=VAL(OMat$)
    poss=VAL(poss$)
    Oposs=VAL(Oposs$)
    designpress=VAL(designpress$)

```

```

IF menuitem=4 OR menuitem=5 THEN
  IF Ri<>OldRi THEN datalsDifferent=1
  IF RO<>OldRO THEN datalsDifferent=1
  IF Mat<>OldMat THEN datalsDifferent=1
  IF FIX(dep)<>FIX(Olddep) THEN datalsDifferent=1
  IF FIX(AutoP)<>FIX(OldautoP) THEN datalsDifferent=1
END IF
IF ((menuitem=7 OR menuitem=8) AND problemtype$="Autofrettage only" )THEN
  IF Ri<>OldRi THEN datalsDifferent=1
  IF RO<>OldRO THEN datalsDifferent=1
  IF Mat<>OldMat THEN datalsDifferent=1
  IF FIX(dep)<>FIX(Olddep) THEN datalsDifferent=1
  IF FIX(AutoP)<>FIX(OldautoP) THEN datalsDifferent=1
END IF
IF ((menuitem=7 OR menuitem=8) AND problemtype$<>"Autofrettage only" )THEN
  IF Ri<>OldRi THEN datalsDifferent=1
  IF RO<>OldRO THEN datalsDifferent=1
  IF Mat<>OldMat THEN datalsDifferent=1
  IF FIX(dep)<>FIX(Olddep) THEN datalsDifferent=1
  IF FIX(AutoP)<>FIX(OldautoP) THEN datalsDifferent=1
  IF ORI<>OldORI THEN datalsDifferent=1
  IF ORO<>OldORO THEN datalsDifferent=1
  IF OMat<>OldOMat THEN datalsDifferent=1
  IF poss<>Oldposs THEN datalsDifferent=1
  IF Oposs<>OldOposs THEN datalsDifferent=1
END IF
IF datalsDifferent=1 THEN
  WINDOW 6," ",(90,65)-(370,165),2
  refreshflag=0
  CALL TEXTFACE(1)
  EDIT FIELD 103,"Input data has been changed
since",(10,20)-(260,35),7,2
  EDIT FIELD 104,"last calculation. Please
reselect",(10,38)-(260,53),7,2
  EDIT FIELD 105,"calculation choice from stress
menu.",(2,56)-(270,71),7,2
  EDIT FIELD 106,"",(1000,1000)-(1020,1020),7,2
  CALL TEXTFACE(0)
  SOUND 220,7,,0
  SOUND 293.5,7,,1
  SOUND 880,7,,2
  SOUND 1174,7,,3
  BUTTON 4 ,1,"OK",(190,80)-(240,95),1
  TIMER OFF
  CALL INITCURSOR
  loop5:
    LET retkey=DIALOG(0)
    IF retkey=1 OR retkey=6 THEN GOTO getoon5
  GOTO loop5
  getoon5:

```

```

        WINDOW CLOSE 6
        datachangedredo=1
    IF problemtype$="Shrinkfit only" THEN
        MENU 6,1,0
        MENU 6,2,0
        MENU 6,4,0
        MENU 6,5,1
        MENU 6,7,0
        MENU 6,8,0
    ELSE
        MENU 6,1,1
        MENU 6,2,1
        MENU 6,4,0
        MENU 6,5,0
        MENU 6,7,0
        MENU 6,8,0
    END IF
END IF
RETURN

' *****
** Draw box around fields and graphs **
' *****
boxinScreen:
forecolor 33
    LINE (box1x1,box1y1)-(box1x2,box1y2),,bf      ***line1
    LINE(box2x1,box2y1)-(box2x2,box2y2),,b        ***line2
    LINE (box3x1,box3y1)-(box3x2,box3y2)          ***line3
    LINE (box4x1,box4y1)-(box4x2,box4y2)          ***line4
    IF macsize$="big" THEN LINE(box5x1,box5y1)-(box5x2,box5y2)
RETURN
' *****

' *****
** Set up user interface fields**
' *****
UserInterface1:
CALL TEXTFACE(8)
EDIT FIELD 55,"Problem Type:          Autofrettage/ShrinkFit",(ef55x1,ef55y1)-
(ef55x2,ef55y2),7,2
GOSUB boxinScreen
CALL TEXTFACE(0)
EDIT FIELD 111,"Inner Radius of Inner Cylinder",(ef111x1,ef111y1)-(ef111x2,ef111y2),3,2
EDIT FIELD 13,"Outer Radius of Inner Cylinder",(ef13x1,ef13y1)-(ef13x2,ef13y2),3,2
EDIT FIELD 14,"Yield Stress of Inner Cylinder",(ef14x1,ef14y1)-(ef14x2,ef14y2),3,2
EDIT FIELD 15,"Pressure That Begins Yielding In Inner Cylinder",(ef15x1,ef15y1)-
(ef15x2,ef15y2),3,1
EDIT FIELD 16,"Pressure That Completes Yielding in Inner Cylinder",(ef16x1,ef16y1)-
(ef16x2,ef16y2),3,1

```

```

EDIT FIELD 17,"Autofrettage Pressure",(ef17x1,ef17y1)-(ef17x2,ef17y2),3,2
EDIT FIELD 18,"Depth of Yielding",(ef18x1,ef18y1)-(ef18x2,ef18y2),3,2
EDIT FIELD 120,"Inner Radius of Outer Cylinder",(ef120x1,ef120y1)-
(ef120x2,ef120y2),3,2
EDIT FIELD 121,"Outer Radius of Outer Cylinder",(ef121x1,ef121y1)-
(ef121x2,ef121y2),3,2
EDIT FIELD 122,"Yield Stress of Outer Cylinder",(ef122x1,ef122y1)-
(ef122x2,ef122y2),3,2
EDIT FIELD 123,"Poisson's Ratio;",(ef123x1,ef123y1)-(ef123x2,ef123y2),3,2
EDIT FIELD 124,"Operating Pressure",(ef124x1,ef124y1)-(ef124x2,ef124y2),3,2
EDIT FIELD 125,"Interface Pressure Caused by Shrink Fit",(ef125x1,ef125y1)-
(ef125x2,ef125y2),3,1
EDIT FIELD 126,"Pressure at which Reyielding will Occur ",(ef126x1,ef126y1)-
(ef126x2,ef126y2),3,1
EDIT FIELD 127,"Factor of Safety in Final Configuration",(ef127x1,ef127y1)-
(ef127x2,ef127y2),3,1
EDIT FIELD 148,"Inner",(ef148x1,ef148y1)-(ef148x2,ef148y2),3,1
EDIT FIELD 149,"Outer",(ef149x1,ef149y1)-(ef149x2,ef149y2),3,1

EDIT FIELD 1,Ri$,(ef1x1,ef1y1)-(ef1x2,ef1y2),2,2
EDIT FIELD 2,RO$,(ef2x1,ef2y1)-(ef2x2,ef2y2),2,2
EDIT FIELD 3,Mat$,(ef3x1,ef3y1)-(ef3x2,ef3y2),2,2
EDIT FIELD 4,AutoP$,(ef4x1,ef4y1)-(ef4x2,ef4y2),2,2
EDIT FIELD 5,dep$,(ef5x1,ef5y1)-(ef5x2,ef5y2),1,2
EDIT FIELD 6,ORIS$,(ef6x1,ef6y1)-(ef6x2,ef6y2),2,2
EDIT FIELD 7,OROS$,(ef7x1,ef7y1)-(ef7x2,ef7y2),2,2
EDIT FIELD 8,OMat$,(ef8x1,ef8y1)-(ef8x2,ef8y2),2,2
EDIT FIELD 9,poss$,(ef9x1,ef9y1)-(ef9x2,ef9y2),2,2
EDIT FIELD 10,Oposs$,(ef10x1,ef10y1)-(ef10x2,ef10y2),2,2
EDIT FIELD 11,DepPress$,(ef11x1,ef11y1)-(ef11x2,ef11y2),2,2
EDIT FIELD 227," ",(700,700)-(720,720),3,1

```

RETURN

'*****'

'*****'

'** Menu Contol **'

'*****'

Menucheck: *** Branch to Menus

menunumber=MENU(0)

menuitem=MENU(1)

MENU

*** turn off menu highlighting

MENU OFF

IF menunumber=1 THEN GOSUB fileMenuBrancher

IF menunumber=2 THEN GOSUB editMenuBrancher

IF menunumber=3 THEN GOSUB reportMenuBrancher

IF menunumber=4 THEN GOSUB yldcritMenuBrancher

IF menunumber=6 THEN GOSUB StressMenuBrancher

IF menunumber=5 THEN GOSUB AutopMenuBrancher

IF menunumber=7 THEN GOSUB meshMenuBrancher

```

IF menunumber=8 THEN GOSUB unitMenuBrancher
EDIT FIELD 227," ",(700,700)-(720,720),3,1
MENU ON
RETURN

```

```

'*****
** Menu Contol for file menu **
'*****

```

```
fileMenuBrancher:
```

```

  IF menuitem=1 THEN
    type1$="PREZ"
    filesave$=FILES$(0)
    GOSUB writedata
    SetCreate filesave$,"PRES"
    NAME filesave$ AS filesave$.type1$
  END IF
  IF menuitem=2 THEN
    refreshflag=0
    fileopen$=FILES$(1,"PREZ")
    GOSUB readdata
    GOSUB clearGraph
    GOSUB clearfields
    GOSUB cleararrays
    GOSUB enableStressmenus3
  END IF

```

```

** Menu Contol for Help Menu **

```

```

  IF menuitem=4 THEN
    GOSUB helpscreen
    GOSUB boxinScreen
  END IF

```

```

  IF menuitem=5 THEN
    STOP
  END IF

```

```
  GOSUB boxinScreen
```

```
RETURN
```

```

'*****
** Menu Contol for edit menu **
'*****

```

```
editMenuBrancher:
```

```

  IF menuitem=1 THEN
    changecursor 4
    yoriginlocation=100
    GOSUB SetGraphLocation
    PICTURE ON
    WINDOW 2, "Under Pressure",(win1x1,win1y1)-(win1x2,win1y2)
    WINDOW OUTPUT 2
    GOSUB refresh
    PICTURE OFF
  END IF

```

```

  IF macsize$="small" THEN
    yoriginlocation=226 *** Set origin of graphs for on screen viewing
  END IF

```

```

ELSE
    yoriginlocation=320
END IF
    GOSUB SetGraphLocation
    OPEN "clip:picture" FOR OUTPUT AS #1
    PRINT #1,PICTURES
    CLOSE #1
    PICTURE ON:PICTURE OFF
    WINDOW CLOSE 2
    CALL INITCURSOR
END IF
IF menuitem=2 THEN
    changecursor 4
    PICTURE ON
        max&=1.3*(4+(SYSTEM(6)+1)*2*INT((SYSTEM(5)+16)/16)/4+1
        IF max&>32767 OR max&*4+60 > FRE(0) THEN
            WINDOW 3,"",(10,106)-(509,338),3
            PRINT "Not Enough Memory in Program Data Block"
            PRINT ""
            INPUT "Press Return To Continue";AS
            WINDOW CLOSE 3
            RETURN
        END IF
        DIM screen&(max&)
        GET (-2,-20)-(565,400),screen&      *** Get only under pressure window
        PUT (0,0)-(400,283),screen&
        ERASE screen&
    PICTURE OFF
    OPEN "clip:picture" FOR OUTPUT AS #1
    PRINT #1,PICTURES
    CLOSE #1
    PICTURE ON:PICTURE OFF
    CALL INITCURSOR
END IF

RETURN

' *****
'** Menu Control for Report Menu      **
' *****

reportMenuBrancher:
    IF menuitem=1 THEN      ***Print Current Screen
        WINDOW 6," ",(90,65)-(370,160),2
        BUTTON 1,1,"Print Entire Screen",(60,15)-(200,40),1
        BUTTON 2,1,"Print Under Pressure Window Only",(15,50)-      (245,75),1
    CALL INITCURSOR

lop4:
LET retkey=DIALOG(0)
LET pushit=DIALOG(1)
IF retkey=1 THEN GOTO buthand

```

GOTO lop4

buthand:

IF pushit=1 THEN wholescreen=1

IF pushit=2 THEN wholescreen=0

WINDOW CLOSE 6

GOSUB boxinScreen

GOSUB PrintScreen

forecolor 33

GOSUB boxinScreen

CALL INITCURSOR

END IF

IF menuitem=2 THEN

***Print Report

changecursor 4

GOSUB printreport

CALL INITCURSOR

END IF

IF menuitem=3 THEN

reportsave\$=FILES\$(0)

IF reportsave\$="" THEN GOTO reportsaveskip

GOSUB writetextreport

SetCreate reportsave\$,"PRES"

NAME reportsave\$ AS reportsave\$,"TEXT"

reportsaveskip:

END IF

IF menuitem=4 THEN

GOSUB printstress

ON ERROR GOTO 0

END IF

IF menuitem=5 THEN

TIMER ON

GOSUB deactivateMenus

GOSUB examinestresses

GOSUB activateMenus

END IF

IF menuitem=6 THEN

report\$=FILES\$(0)

IF report\$="" THEN GOTO textreportskip

GOSUB writereport

SetCreate report\$,"PRES"

NAME report\$ AS report\$,"REPO"

textreportskip:

END IF

GOSUB boxinScreen

RETURN

```

' *****
** Menu Contol for yieldcriteria menu          **
' *****

yldcritMenuBrancher:
  IF menuitem=1 THEN
    currentyeildcrit$="Tresca"
    MENU 4,1,2,"Tresca"
    MENU 4,2,1,"Von Mises"
  END IF

  IF menuitem=2 THEN
    currentyeildcrit$="Von Mises"
    MENU 4,1,1,"Tresca"
    MENU 4,2,2,"Von Mises"
  END IF
RETURN
' *****

' *****
** Menu Contol for stress menu                **
' *****

StressMenuBrancher:
GOSUB boxinScreen
GOSUB datacheck
IF datachangedredo=1 THEN RETURN
crfl=0
GOSUB getdata1
IF dep=0 AND problemtype$="Both" AND crfl=0 THEN GOSUB depZeroError
IF dep=0 AND problemtype$="Both" AND crfl=0 THEN RETURN
crfl=0
IF menuitem=1 THEN
  BEEP
  withPresFlag=1
  IF depthorpres=1 THEN GOSUB depcalc
  IF depthorpres=2 THEN GOSUB aprscalc
  IF errorflag=1 THEN CALL INITCURSOR:RETURN
  GOSUB FactorSafeClear
  GOSUB stresscalc
  CALL INITCURSOR
END IF
IF menuitem=2 THEN
  withPresFlag=0
  IF depthorpres=1 THEN GOSUB depcalc
  IF depthorpres=2 THEN GOSUB aprscalc
  IF errorflag=1 THEN CALL INITCURSOR: RETURN
  GOSUB FactorSafeClear
  GOSUB stresscalc
  CALL INITCURSOR

```

```

END IF
IF menuitem=4 THEN
  TIMER ON
  Resshrinkflag=0
  GOSUB FactorSafeClear
  GOSUB shrinkpres
  IF errorflag=1 THEN TIMER OFF:CALL INTCURSOR:RETURN
  TIMER OFF
  CALL INTCURSOR
END IF
IF menuitem=5 THEN
  Resshrinkflag=1
  TIMER ON
  GOSUB yieldprop
  GOSUB FactorSafeClear
  GOSUB shrinkpres
  IF errorflag=1 THEN TIMER OFF: CALL INTCURSOR:RETURN
  TIMER OFF
  CALL INTCURSOR
END IF
IF menuitem=7 THEN
  TIMER ON
  GOSUB FactorSafeClear
  GOSUB firstdesprescalc
  IF errorflag=1 THEN TIMER OFF: CALL INTCURSOR:RETURN
  TIMER OFF
  CALL INTCURSOR
END IF
IF menuitem=8 THEN
  resdesignflag=1
  TIMER ON
  Factor$=""
  EDIT FIELD 129,Factor$,(ef129x1,ef129y1)-(ef129x2,ef129y2),3,2
  GOSUB firstdesprescalc
  IF errorflag=1 THEN TIMER OFF :CALL INTCURSOR:RETURN
  TIMER OFF
  CALL INTCURSOR
END IF

RETURN
'*****

'*****
** Menu Contol for autoP Menu **
'*****

AutopMenuBrancher:
  IF menuitem=1 THEN
    MENU 5,1,2,"User Supplies Autofrettage pressure"
    MENU 5,2,1,"User Supplies Depth Of Yielding"
    MENU 5,3,1,"Calculate Depth of Yielding"
    EDIT FIELD 4,AutoP$,(ef4x1,ef4y1)-(ef4x2,ef4y2),2,2

```

```

    depthorpres=1
END IF

IF menuitem=2 THEN
    MENU 5,1,1,"User Supplies Autofrettage pressure"
    MENU 5,2,2,"User Supplies Depth Of Yielding"
    MENU 5,3,1,"Calculate Autofrettage Pressure"
    EDIT FIELD 5,dep$,(ef5x1,ef5y1)-(ef5x2,ef5y2),1,2
    depthorpres=2
END IF

IF menuitem=3 THEN
    IF depthorpres=1 THEN
        changecursor 4
        GOSUB depcalc
        CALL INITCURSOR
    END IF
    IF depthorpres=2 THEN GOSUB aprscalc
END IF

IF menuitem=4 THEN
    GOSUB yieldprop
END IF

IF menuitem=6 THEN
    problemtype$="Autofrettage only"
    MENU 5,6,2,"AutoFrettage only"
    MENU 5,7,1,"Shrinkfit only"
    MENU 5,8,1,"Shrinkfit and AutoFrettage"
    MENU 6,1,1,"Stress With Autofrettage pressure(Inner Cylinder)"
    MENU 6,2,1,"Residual Stress After Autofrettage(Inner Cylinder)"
    MENU 6,4,0,"Stress due to Shrink Fit Only"
    MENU 6,5,0,"Total Stress After Shrink Fit"
    MENU 6,7,0,"Stress From Operating Pressure Only"
    MENU 6,8,0,"Total Stress With Operating Pressure"
    CALL TEXTFACE(8)
    EDIT FIELD 55,"Problem Type:      Autofrettage  Only", (ef55x1,ef55y1)-
    (ef55x2,ef55y2),7,2
    CALL TEXTFACE(0)
    GOSUB FactorSafeClear
    GOSUB clearGraph
    GOSUB cleararrays
    GOSUB clearfields
END IF

IF menuitem=7 THEN
    problemtype$="Shrinkfit only"
    changecursor 4
    GOSUB nostress
    MENU 5,6,1
    MENU 5,7,2

```

```

MENU 5,8,1
MENU 6,1,0
MENU 6,2,0
MENU 6,4,0
MENU 6,5,1
MENU 6,7,0
MENU 6,8,0
CALL TEXTFACE(8)
  EDIT FIELD 55,"Problem Type:      ShrinkFit      Only", (cf55x1,cf55y1)-
    (cf55x2,cf55y2),7,2
CALL TEXTFACE(0)
  GOSUB FactorSafeClear
  GOSUB clearGraph
  GOSUB cleararrays
  GOSUB clearfields
CALL INTCURSOR
END IF

IF menuitem=8 THEN
  problemtype$="Both"
  MENU 5,6,1,"AutoFrettag only"
  MENU 5,7,1,"Shrinkfit only"
  MENU 5,8,2,"Shrinkfit and AutoFrettag"
  MENU 6,1,1,"Stress With Autofrettag pressure(Inner Cylinder)"
  MENU 6,2,1,"Residual Stress After Autofrettag(Inner Cylinder)"
  MENU 6,4,0,"Stress due to Shrink Fit Only"
  MENU 6,5,0,"Total Stress After Shrink Fit"
  MENU 6,7,0,"Stress From Operating Pressure Only"
  MENU 6,8,0,"Total Stress With Operating Pressure"
CALL TEXTFACE(8)
  EDIT FIELD 55,"Problem Type:      Autofrettag/ShrinkFit", (cf55x1,cf55y1)-
    (cf55x2,cf55y2),7,2
CALL TEXTFACE(0)
  GOSUB FactorSafeClear
  GOSUB clearGraph
  GOSUB cleararrays
  GOSUB clearfields
END IF

RETURN
*****

'*****

'*** Menu Contol for Mesh Menu      **
'*****

meshMenuBrancher:
  IF menuitem=1 THEN

    WINDOW 2,"Mesh",(50,40)-(435,150),1
    BUTTON 30 ,1,"OK",(300,85)-(340,105),1

```

```

oldinner=Innermesh
oldouter=Outermesh
Innermesh$=STR$(Innermesh)
Outermesh$=STR$(Outermesh)
EDIT FIELD 98,"Inner Cylinder Mesh",(10,10)-(170,25),7,2
EDIT FIELD 99,"Outer Cylinder Mesh",(10,40)-(170,55),7,2
EDIT FIELD 2,Outermesh$(180,40)-(220,55),1,2
EDIT FIELD 1,Innermesh$(180,10)-(220,25),1,2
m=0
EDIT FIELD m+1

loop30:
  LET retkey=DIALOG(0)
  LET pushed2=DIALOG(1)
  IF retkey=7 OR 2 THEN GOSUB fld2
  IF retkey=1 OR retkey=6 THEN GOTO geton
GOTO loop30
fld2:
  IF retkey=7 THEN m=m+1 : EDIT FIELD 1+m MOD 2
  IF retkey=2 THEN m=DIALOG(2)-1
RETURN

geton:
  changecursor 4
  Innermesh$=EDIT$(1)
  Outermesh$=EDIT$(2)
  Innermesh=VAL(Innermesh$)
  innermeshplus=Innermesh+1
  Outermesh=VAL(Outermesh$)
  outermeshplus=Outermesh+1
  IF oldinner=Innermesh AND oldouter=Outermesh THEN GOTO Jumpover
  GOSUB undimension
  GOSUB dimension
  Jumpover:
  WINDOW CLOSE 2
  GOSUB boxinScreen
  CALL INITCURSOR
END IF

RETURN
' *****
** Menu Control for Units Menu **
' *****

unitMenuBrancher:
  IF menuitem=1 THEN
    LengthUnit$=" in"
    PresUnit$=" psi"
  MENU 8,1,2
  MENU 8,2,1
  WINDOW 2,"Units",(50,40)-(435,150),1
  BUTTON 30 ,1,"OK",(300,85)-(340,105),1

```

```

CALL TEXTFACE(1)
PRINT ""
PRINT "          English System"
PRINT ""
PRINT "          Enter Lengths in Inches"
PRINT "          Enter Pressure or Stress in psi"
CALL TEXTFACE(0)
loopU:
    LET retkey=DIALOG(0)
    IF retkey=1 OR retkey=6 THEN GOTO getonwithitU
GOTO loopU
getonwithitU:
WINDOW CLOSE 2
GOSUB boxinScreen

END IF
IF menuitem=2 THEN
    LengthUnit$=" mm"
    PresUnit$=" MPa"
    MENU 8,1,1
    MENU 8,2,2
    WINDOW 2,"Units",(50,40)-(435,150),1
    BUTTON 30 ,1,"OK",(300,85)-(340,105),1
    CALL TEXTFACE(1)
    PRINT ""
    PRINT "          SI System"
    PRINT ""
    PRINT "          Enter Lengths in mm"
    PRINT "          Enter Pressure or Stress in MPa"
    CALL TEXTFACE(0)
    loopU2:
        LET retkey=DIALOG(0)
        IF retkey=1 OR retkey=6 THEN GOTO getonwithitU2
    GOTO loopU2
    getonwithitU2:
WINDOW CLOSE 2
GOSUB boxinScreen

END IF

RETURN

```

```

' *****
'** Calculate pressure at which yeilding begins **
'** and when cylinder is fully plastic **
' *****
yieldprop:
GOSUB getData0
IF errorflag=1 THEN RETURN
    IF currentyeildcrit$="Tresca" THEN TwiceTau=Mat

```

```

IF currentyeildcrit$="von Mises" THEN      TwiceTau=(2/(3^(1/2)))*Mat
yieldbeg=TwiceTau*((RO^2-Ri^2)/(2*RO^2))
yieldfin=TwiceTau*LOG(RO/Ri)
yieldbeg$=STR$(yieldbeg)
yieldbeg$=LEFT$(yieldbeg$,10)
yieldfin$=STR$(yieldfin)
yieldfin$=LEFT$(yieldfin$,10)
EDIT FIELD 21,yieldbeg$(ef21x1,ef21y1)-(ef21x2,ef21y2),2,2
EDIT FIELD 22,yieldfin$(ef22x1,ef22y1)-(ef22x2,ef22y2),2,2
RETURN
'*****

'*****
** subroutine to calculate autofrettage pressure**
'*****

aprsclc:
GOSUB getData0
IF errorflag=1 THEN RETURN
GOSUB yieldprop
dep$=EDIT$(5)
dep=VAL(dep$)
firstinterval=Ri+((RO-Ri)/Innermesh)
IF dep > Ri AND dep < firstinterval THEN
    dep=firstinterval
    dep$=STR$(dep)
    EDIT FIELD 5,dep$(ef5x1,ef5y1)-(ef5x2,ef5y2),1,2
END IF

'***** errortrap
IF (dep>RO) THEN GOSUB errortrap
IF errorflag=1 THEN RETURN
GOSUB enablestressmenus0
IF currentyeildcrit$="Tresca" THEN TwiceTau=Mat
IF currentyeildcrit$="von Mises" THEN TwiceTau=(2/(3^(1/2)))*Mat
IF dep>=Ri THEN
    AutoP=TwiceTau*(LOG(dep/Ri)+((RO^2-dep^2)/(2*RO^2)))
    AutoP$=STR$(AutoP)
    AutoP$=LEFT$(AutoP$,10)
    EDIT FIELD 4,AutoP$(ef4x1,ef4y1)-(ef4x2,ef4y2),2,2
ELSE
    AutoP$="0"
    EDIT FIELD 4,AutoP$(ef4x1,ef4y1)-(ef4x2,ef4y2),2,2
END IF

RETURN
'*****

'*****
** bisection routine to find depth of yeilding **
'*****

depcalc:

```

```

GOSUB getData0
IF errorflag=1 THEN RETURN
GOSUB yieldprop
AutoP$=EDIT$(4)
AutoP=VAL(AutoP$)
  IF (AutoP < yieldbeg) THEN dep=0 : GOTO solved
  IF (AutoP > yieldfin) THEN
    AutoP=yieldfin
    dep=RO
    AutoP$=STR$(AutoP)
    AutoP$=LEFT$(AutoP$,10)
    EDIT FIELD 4,AutoP$,(ef4x1,ef4y1)-(ef4x2,ef4y2),2,2
    GOTO solved
  END IF
GOSUB enablestressmenus0
IF currentyeildcrit$="Tresca" THEN TwiceTau=Mat
IF currentyeildcrit$="von Mises" THEN TwiceTau=(2/(3^(1/2)))*Mat
i=0
XL=Ri
XR=RO
XM=Ri + ((RO-Ri)/2)
Tolerance=(RO-Ri)/100
Funcnclalc:
  FXL=TwiceTau*((LOG(XL/Ri)+((RO^2-XL^2)/(2*RO^2))))-AutoP
  FXR=TwiceTau*((LOG(XR/Ri)+((RO^2-XR^2)/(2*RO^2))))-AutoP
  FXM=TwiceTau*((LOG(XM/Ri)+((RO^2-XM^2)/(2*RO^2))))-AutoP
  IF FXM=0 THEN dep=XM : GOTO solved
  T1=FXL*FXM
  T2=FXM*FXR
  IF ABS(FXM)< Tolerance THEN dep = XM : GOTO solved
  IF T1<0 THEN XL=XL:XR=XM:XM=XL+(XR-XL)/2
  IF T2<0 THEN XL=XM:XR=XR:XM=XL+(XR-XL)/2
  GOTO Funcnclalc
solved:
  firstinterval=Ri+((RO-Ri)/Innermesh)
  IF dep > Ri AND dep < firstinterval THEN dep=firstinterval
  dep1$=STR$(dep)
  dep$=LEFT$(dep1$,7)
  EDIT FIELD 5,dep$,(ef5x1,ef5y1)-(ef5x2,ef5y2),1,2
RETURN
' *****

' *****
** Enable menus according to problem type **
' *****

enablestressmenus0:
MENU 6,1,1
MENU 6,2,1
RETURN
enablestressmenus:

```

```

IF problemtype$ <> "Autofrettage only" THEN
  MENU 6,4,1
  MENU 6,5,1
  MENU 6,7,0
  MENU 6,8,0
END IF
RETURN
enablestressmenus2:
  MENU 6,7,1
  MENU 6,8,1
RETURN
enableStressmenus3:
  MENU 6,4,0
  MENU 6,5,0
  MENU 6,7,0
  MENU 6,8,0
  IF problemtype$="Shrinkfit only" THEN
    MENU 6,1,0
    MENU 6,2,0
    MENU 6,5,1
  END IF
RETURN
'*****
** Graphing for residual autofrettage *****
'*****
resautograph:
GOSUB coordinatesystem
  CALL TEXTFACE(1)
  EDIT FIELD 200,"Stress After Autofrettage Pressure Is Released (Inner
Cylinder)",((Tit1-25),Tit2)-(Tit3,Tit4),7,2
  CALL TEXTFACE(0)
GOSUB maxstressRA
GOSUB printmaxi
rspan=RO-Ri
IF Rmax=0 THEN Rmax=1
FOR i=1 TO innermeshplus
  x(i)=(((Ressigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
  y(i)=(-1*((Ressigma(2,i)/Rmax)*RySpan))+rStarty
NEXT i
GOSUB drawline1
IF Tmax=0 THEN Tmax=1
FOR i=1 TO innermeshplus
  x(i)=(((Ressigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
  y(i)=(-1*((Ressigma(3,i)/Tmax)*HySpan))+hStarty
NEXT i
GOSUB drawline1
CALL TEXTSIZE(12)
RETURN
'*****
** Find Max Stresses for residual autofrettage *****

```

```

*****
maxstressRA:
Rmax=ABS(Ressigma(2,1))
Tmax=ABS(Ressigma(3,1))      'find max stress
maxlocationRares=1
maxlocationTares=1
FOR i = 2 TO innermeshplus
    IF ABS(Ressigma(2,i))>Rmax THEN
        Rmax=ABS(Ressigma(2,i))
        maxlocationRares=i
    END IF
    IF ABS(Ressigma(3,i))>Tmax THEN
        Tmax=ABS(Ressigma(3,i))
        maxlocationTares=i
    END IF
NEXT i
RETURN

*****
** Graphing for with autofrettage pressure ***
*****
graphwithpres:
GOSUB coordinatesystem
    CALL TEXTFACE(1)
    EDIT FIELD 200,"Stress With Autofrettage Pressure(Inner
    Cylinder)",(Tit1,Tit2)-(Tit3,Tit4),7,2
    CALL TEXTFACE(0)
GOSUB maxstressA:
GOSUB printmaxi
rspan=RO-Ri
IF Rmax=0 THEN Rmax=1
FOR i=1 TO innermeshplus
    x(i)=(((sigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
    y(i)=(-1*((sigma(2,i)/Rmax)*RySpan))+rStarty
NEXT i
GOSUB drawline1
IF Tmax=0 THEN Tmax=1
FOR i=1 TO innermeshplus
    x(i)=(((sigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
    y(i)=(-1*((sigma(3,i)/Tmax)*HySpan))+hStarty
NEXT i
GOSUB drawline1
CALL TEXTSIZE(12)
RETURN

*****
** Find Max Stresses with autofrettage *****
*****
maxstressA:
Rmax=ABS(sigma(2,1))
Tmax=ABS(sigma(3,1))      ' find max stress

```

```

maxlocationR=1
maxlocationT=1
FOR i = 2 TO innermeshplus
  IF ABS(sigma(2,i))>Rmax THEN
    Rmax=ABS(sigma(2,i))
    maxlocationR=i
  END IF
  IF ABS(sigma(3,i))>Tmax THEN
    Tmax=ABS(sigma(3,i))
    maxlocationT=i
  END IF
NEXT i
RETURN

```

```

'*****
**  print shrink only graph          *****
'*****

shrinkprnt:
GOSUB coordinatesystem2
  CALL TEXTFACE(1)
  EDIT FIELD 200,"Stress Caused By Shrink Fit Only", (Tit1,Tit2)- (Tit3,Tit4),7,2
  CALL TEXTFACE(0)
GOSUB maxstressSO:
Rmax=SRmax
Tmax=STmax
GOSUB printmaxi
rspan=ORO-Ri
lspan=((RO-Ri)/rspan)*190
jacketspan=((ORO-RO)/rspan)*190
FOR i=1 TO innermeshplus
  x(i)=(((shrksigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
  y(i)=(-1*((shrksigma(2,i)/SRmax)*RySpan))+rStarty
NEXT i
FOR i=1 TO outermeshplus
  Q(i)=(((jshrksigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
  R(i)=(-1*((jshrksigma(2,i)/SRmax)*RySpan))+rStarty
NEXT i
GOSUB drawline2
FOR i=1 TO innermeshplus
  x(i)=(((shrksigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
  y(i)=(-1*((shrksigma(3,i)/STmax)*HySpan))+hStarty
NEXT i
FOR i=1 TO outermeshplus
  Q(i)=(((jshrksigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
  R(i)=(-1*((jshrksigma(3,i)/STmax)*HySpan))+hStarty
NEXT i
GOSUB drawline2
CALL TEXTSIZE(12)
RETURN

```

```

*****
** Find Max Stresses for shrinkfit only *****
*****
maxstressSO:
SRmax=ABS(shrksigma(2,1))
STmax=ABS(shrksigma(3,1))      ' find max stress
FOR i = 2 TO innermeshplus
    IF ABS(shrksigma(2,i))>SRmax THEN SRmax=ABS(shrksigma(2,i))
    IF ABS(shrksigma(3,i))>STmax THEN STmax=ABS(shrksigma(3,i))
NEXT i
maxlocationRjsres=1
maxlocationTjsres=1
FOR i = 1 TO outermeshplus
    IF ABS(jshrksigma(2,i))>SRmax THEN
        SRmax=ABS(jshrksigma(2,i))
        maxlocationRjsres=i
    END IF
    IF ABS(jshrksigma(3,i))>STmax THEN
        STmax=ABS(jshrksigma(3,i))
        maxlocationTjsres=i
    END IF
NEXT i
RETURN

*****
** print residual shrink graph *****
*****
resshrinkprnt:
GOSUB coordinatesystem2
    CALL TEXTFACE(1)
    EDIT FIELD 200,"Total Stress After Shrinkfit",(Tit1,Tit2)-      (Tit3,Tit4),7,2
    CALL TEXTFACE(0)
GOSUB maxstressjshrk
GOSUB maxstressRS

Rmax=SRmax
Tmax=STmax
GOSUB printmaxi
rspan=ORO-Ri
linspan=((RO-Ri)/rspan)*190
jacketspan=((ORO-RO)/rspan)*190
FOR i=1 TO innermeshplus
    x(i)=(((Resshrksigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
    y(i)=(-1*((Resshrksigma(2,i)/SRmax)*RySpan))+rStarty
NEXT i
FOR i=1 TO outermeshplus
    Q(i)=(((jshrksigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
    R(i)=(-1*((jshrksigma(2,i)/SRmax)*RySpan))+rStarty
NEXT i
GOSUB drawline2
FOR i=1 TO innermeshplus

```

```

        x(i)=((Resshrksigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
        y(i)=(-1*((Resshrksigma(3,i)/STmax)*HySpan))+hStarty
NEXT i
FOR i=1 TO outermeshplus
    Q(i)=((jshrksigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
    R(i)=(-1*((jshrksigma(3,i)/STmax)*HySpan))+hStarty
NEXT i
GOSUB drawline2
CALL TEXTSIZE(12)
RETURN

'*****
** Find Max Stresses for residual shrinkfit *****
'*****

maxstressRS:
SRmax=ABS(Resshrksigma(2,1))
STmax=ABS(Resshrksigma(3,1))      ' find max stress
maxlocationRsres=1
maxlocationTsres=1
FOR i = 2 TO innermeshplus
    IF ABS(Resshrksigma(2,i))>SRmax THEN
        SRmax=ABS(Resshrksigma(2,i))
        maxlocationRsres=i
    END IF
    IF ABS(Resshrksigma(3,i))>STmax THEN
        STmax=ABS(Resshrksigma(3,i))
        maxlocationTsres=i
    END IF
NEXT i
FOR i = 1 TO outermeshplus
    IF ABS(jshrksigma(2,i))>SRmax THEN SRmax=ABS(jshrksigma(2,i))
    IF ABS(jshrksigma(3,i))>STmax THEN STmax=ABS(jshrksigma(3,i))
NEXT i

'***** find max stress location in outer cylinder for report
Routmax=ABS(jshrksigma(2,1))
Toutmax=ABS(jshrksigma(3,1))
OmaxlocationRsres=1
OmaxlocationTsres=1
FOR i = 2 TO outermeshplus
    IF ABS(jshrksigma(2,i))>Routmax THEN
        OmaxlocationRsres=i
        Routmax=ABS(jshrksigma(2,i))
    END IF
    IF ABS(jshrksigma(3,i))>Toutmax THEN
        OmaxlocationTsres=i
        Toutmax=ABS(jshrksigma(3,i))
    END IF
NEXT i
RETURN

```

```

*****
** print design pressure only graph *****
*****
designPrnt:
    GOSUB coordinatesystem2
    CALL TEXTFACE(1)
    EDIT FIELD 200,"Stress Due To Operating Pressure Only",(Tit1,Tit2)-(Tit3,Tit4),7,2
    CALL TEXTFACE(0)
GOSUB maxstressOPO:

Rmax=SRmax
Tmax=STmax
GOSUB printmaxi
rspan=ORO-Ri
linspan=((RO-Ri)/rspan)*190
jacketspan=((ORO-RO)/rspan)*190
FOR i=1 TO innermeshplus
    x(i)=(((designsigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
    y(i)=(-1*((designsigma(2,i)/SRmax)*RySpan))+rStarty
NEXT i
FOR i=1 TO outermeshplus
    Q(i)=(((jdesignsigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
    R(i)=(-1*((jdesignsigma(2,i)/SRmax)*RySpan))+rStarty
NEXT i
GOSUB drawline2
FOR i=1 TO innermeshplus
    x(i)=(((designsigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
    y(i)=(-1*((designsigma(3,i)/STmax)*HySpan))+hStarty
NEXT i
FOR i=1 TO outermeshplus
    Q(i)=(((jdesignsigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
    R(i)=(-1*((jdesignsigma(3,i)/STmax)*HySpan))+hStarty
NEXT i
GOSUB drawline2
CALL TEXTSIZE(12)
RETURN

*****
** Find Max Stresses for operating pressure only *****
*****
maxstressOPO:
ImaxRdoLoc=1
ImaxTdoLoc=1
OmaxRdoLoc=1
OmaxTdoLoc=1
SRmax=ABS(designsigma(2,1))
STmax=ABS(designsigma(3,1)) ' find max stress
FOR i = 2 TO innermeshplus
    IF ABS(designsigma(2,i))>SRmax THEN
        SRmax=ABS(designsigma(2,i))
        ImaxRdoLoc=i

```

```

END IF
  IF ABS(designsigma(3,i))>STmax THEN
    STmax=ABS(designsigma(3,i))
    ImaxTdoLoc=i
  END IF
NEXT i
FOR i = 1 TO outermeshplus
  IF ABS(jdesignsigma(2,i))>SRmax THEN
    SRmax=ABS(jdesignsigma(2,i))
    OmaxRdoLoc=i
  END IF
  IF ABS(jdesignsigma(3,i))>STmax THEN
    STmax=ABS(jdesignsigma(3,i))
    OmaxTdoLoc=i
  END IF
NEXT i
FOR i = 1 TO outermeshplus
  IF ABS(jdesignsigma(2,i))>SRmax THEN SRmax=ABS(jdesignsigma(2,i))
  IF ABS(jdesignsigma(3,i))>STmax THEN STmax=ABS(jdesignsigma(3,i))
NEXT i

'***** find max stress location in outer cylinder for report
Routmax=ABS(jdesignsigma(2,1))
Toutmax=ABS(jdesignsigma(3,1))
OmaxRdoLoc=1
OmaxTdoLoc=1
FOR i = 2 TO outermeshplus
  IF ABS(jdesignsigma(2,i))>Routmax THEN
    OmaxRdoLoc=i
    Routmax=ABS(jshrksigma(2,i))
  END IF
  IF ABS(jdesignsigma(3,i))>Toutmax THEN
    OmaxTdoLoc=i
    Toutmax=ABS(jshrksigma(3,i))
  END IF
NEXT i
RETURN

'*****
** print residual design graph *****
'*****
resdesignPrnt:
  GOSUB coordinatesystem2
  CALL TEXTFACE(1)
  EDIT FIELD 200,"Total Stress With Operating Pressure Applied",(Tit1,Tit2)-
(Tit3,Tit4),7,2
  CALL TEXTFACE(0)
  GOSUB maxstressROP:
Rmax=SRmax
Tmax=STmax

```

```

GOSUB printmaxi
rspan=ORO-Ri
linspan=((RO-Ri)/rspan)*190
jacketspan=((ORO-RO)/rspan)*190
FOR i=1 TO innermeshplus
    x(i)=(((Resdesignsigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
    y(i)=(-1*((Resdesignsigma(2,i)/SRmax)*RySpan))+rStarty
NEXT i
FOR i=1 TO outermeshplus
    Q(i)=(((jResdesignsigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
    R(i)=(-1*((jResdesignsigma(2,i)/SRmax)*RySpan))+rStarty
NEXT i
GOSUB drawline2
FOR i=1 TO innermeshplus
    x(i)=(((Resdesignsigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
    y(i)=(-1*((Resdesignsigma(3,i)/STmax)*HySpan))+hStarty
NEXT i
FOR i=1 TO outermeshplus
    Q(i)=(((jResdesignsigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
    R(i)=(-1*((jResdesignsigma(3,i)/STmax)*HySpan))+hStarty
NEXT i
GOSUB drawline2
CALL TEXTSIZE(12)
RETURN

```

```

'*****
** Find Max Stresses for residual after operating pressure**
'*****
maxstressROP:
ImaxRL=1
ImaxTL=1
OmaxRL=1
OmaxTL=1
SRmax=ABS(Resdesignsigma(2,1))
STmax=ABS(Resdesignsigma(3,1))      ' find max stress
FOR i = 2 TO innermeshplus
    IF ABS(Resdesignsigma(2,i))>SRmax THEN
        SRmax=ABS(Resdesignsigma(2,i))
        ImaxRL=i
    END IF
    IF ABS(Resdesignsigma(3,i))>STmax THEN
        STmax=ABS(Resdesignsigma(3,i))
        ImaxTL=i
    END IF
NEXT i
FOR i = 1 TO outermeshplus
    IF ABS(jResdesignsigma(2,i))>SRmax THEN
        SRmax=ABS(jResdesignsigma(2,i))
        OmaxRL=i
    END IF
    IF ABS(jResdesignsigma(3,i))>STmax THEN

```

```

        STmax=ABS(jResdesignsigma(3,i))
        OmaxTL=i
    END IF
NEXT i
RETURN

'*****
** print maximum and minimum stresses on graph *****
'*****

printmaxi:
    Rmax=FIX(Rmax)
    Tmax=FIX(Tmax)
    NegRmax=-1*Rmax
    NegTmax=-1*Tmax
    negmaxrad$=STR$(NegRmax)
    negmaxrad$=LEFT$(negmaxrad$,10)
    neghoopmax$=STR$(NegTmax)
    neghoopmax$=LEFT$(neghoopmax$,10)
    maxrad$=STR$(Rmax)
    maxrad$=LEFT$(maxrad$,10)
    hoopmax$=STR$(Tmax)
    hoopmax$=LEFT$(hoopmax$,10)
    CALL TEXTSIZE(9)
    EDIT FIELD 32,negmaxrad$,(ef32x1,ef32y1)-(ef32x2,ef32y2),3,2
    EDIT FIELD 39,maxrad$,(ef39x1,ef39y1)-(ef39x2,ef39y2),3,2
    EDIT FIELD 40,hoopmax$,(ef40x1,ef40y1)-(ef40x2,ef40y2),3,2
    EDIT FIELD 41,neghoopmax$,(ef41x1,ef41y1)-(ef41x2,ef41y2),3,2
    CALL TEXTSIZE(12)
RETURN

'*****
** draw lines for inner cylinder *****
'*****

drawline1:
FOR i=1 TO Innermesh
    X1=x(i)
    Y1=y(i)
    X2=x(i+1)
    Y2=y(i+1)
    GOSUB ChangeColorRed
    LINE(X1,Y1)-(X2,Y2)
    forecolor 33
NEXT i
RETURN

'*****
** draw lines for both cylinders *****
'*****

drawline2:
FOR i=1 TO Innermesh
    X1=x(i)

```

```

Y1=y(i)
X2=x(i+1)
Y2=y(i+1)
  GOSUB ChangeColorRed
  LINE(X1,Y1)-(X2,Y2)
  forecolor 33
NEXT i
FOR i=1 TO Outermesh
  Q1=Q(i)
  R1=R(i)
  Q2=Q(i+1)
  R2=R(i+1)
  GOSUB ChangeColorGreen
  LINE(Q1,R1)-(Q2,R2)
  forecolor 33
NEXT i
RETURN

'*****
'**** graph for autofretage only, stress caused by      ***
'**** design pressure only                               ***
'*****

designAutoPrnt:
GOSUB coordinatesystem
  CALL TEXTFACE(1)
  EDIT FIELD 200,"Stress Due to Operating Pressure Only",(Tit1,Tit2)-(Tit3,Tit4),7,2
  CALL TEXTFACE(0)
  maxlocationAdeR=1
  maxlocationAdeT=1
SRmax=ABS(designsigma(2,1))
STmax=ABS(designsigma(3,1))      ' find max stress
FOR i = 2 TO innermeshplus
  IF ABS(designsigma(2,i))>SRmax THEN
    SRmax=ABS(designsigma(2,i))
    maxlocationAdeR=i
  END IF
  IF ABS(designsigma(3,i))>STmax THEN
    STmax=ABS(designsigma(3,i))
    maxlocationAdeT=i
  END IF
NEXT i
Rmax=SRmax
Tmax=STmax
GOSUB printmaxi
rspan=RO-Ri
IF Rmax=0 THEN Rmax=1
FOR i=1 TO innermeshplus
  x(i)=(((designsigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
  y(i)=(-1*(((designsigma(2,i)/Rmax)*RySpan))+rStarty
NEXT i
GOSUB drawline1

```

```

IF Tmax=0 THEN Tmax=1
FOR i=1 TO innermeshplus
    x(i)=(((designsigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
    y(i)=-1*(((designsigma(3,i)/Tmax)*HySpan))+hStarty
NEXT i
GOSUB drawline1
CALL TEXTSIZE(12)
RETURN

'*****
'**** graph for autofrettage only, stress caused by ***
'**** design pressure and autofrettage ***
'*****

AresdesignPrnt:
GOSUB coordinatesystem
CALL TEXTFACE(1)
EDIT FIELD 200,"Total Stress With Operating Pressure Applied ",(Tit1,Tit2)-
(Tit3,Tit4),7,2
CALL TEXTFACE(0)
maxlocationAAresT=1
maxlocationAAresR=1
SRmax=ABS(Resdesignsigma(2,1))
STmax=ABS(Resdesignsigma(3,1)) ' find max stress
FOR i = 2 TO innermeshplus
    IF ABS(Resdesignsigma(2,i))>SRmax THEN
        SRmax=ABS(Resdesignsigma(2,i))
        maxlocationAAresR=i
    END IF
    IF ABS(Resdesignsigma(3,i))>STmax THEN
        STmax=ABS(Resdesignsigma(3,i))
        maxlocationAAresT=i
    END IF
NEXT i
Rmax=SRmax
Tmax=STmax
GOSUB printmaxi
rspan=RO-Ri
IF Rmax=0 THEN Rmax=1
FOR i=1 TO innermeshplus
    x(i)=(((Resdesignsigma(1,i)-Ri)/rspan)*RxSpan)+rStartx
    y(i)=-1*(((Resdesignsigma(2,i)/Rmax)*RySpan))+rStarty
NEXT i
GOSUB drawline1
IF Tmax=0 THEN Tmax=1
FOR i=1 TO innermeshplus
    x(i)=(((Resdesignsigma(1,i)-Ri)/rspan)*HxSpan)+hStartx
    y(i)=-1*(((Resdesignsigma(3,i)/Tmax)*HySpan))+hStarty
NEXT i
GOSUB drawline1
CALL TEXTSIZE(12)
RETURN

```

```

'*****
** clear fields **
'*****

clearfields:
    Reyielding$=""
    Factor$=""
    mrt$=""
    Ipres$=""
    yieldbeg$=""
    yieldfin$=""
    EDIT FIELD 128,Reyielding$ ,(ef128x1,ef128y1)- (ef128x2,ef128y2),3,2
    EDIT FIELD 129,Factor$,(ef129x1,ef129y1)- (ef129x2,ef129y2),3,2
    EDIT FIELD 56,"",(ef56x1,ef56y1)-(ef56x2,ef56y2),3,1
    EDIT FIELD 57,mrt$,(ef57x1,ef57y1)-(ef57x2,ef57y2),3,1
    EDIT FIELD 205,Ipres$,(ef205x1,ef205y1)-(ef205x2,ef205y2),3,2
    EDIT FIELD 21,yieldbeg$,(ef21x1,ef21y1)-(ef21x2,ef21y2),3,2
    EDIT FIELD 22,yieldfin$,(ef22x1,ef22y1)-(ef22x2,ef22y2),3,2
    rectangle%(0)=104
    rectangle%(1)=332
    rectangle%(2)=188
    rectangle%(3)=453
    CALL ERASERECT(VARPTR(rectangle%(0)))

RETURN

'*****
** clear old graphs **
'*****

clearGraph:
IF cleargraphflag=0 THEN
    IF macsize$="small" THEN
        rectangle%(0)=165
        rectangle%(1)=0
        rectangle%(2)=289
        rectangle%(3)=489
    ELSE
        rectangle%(0)=259
        rectangle%(1)=0
        rectangle%(2)=394
        rectangle%(3)=489
    END IF
    EDIT FIELD CLOSE 200
    CALL ERASERECT(VARPTR(rectangle%(0)))
    END IF
RETURN

'*****
*** Read data from the user input fields ****
'*****

getData0:

```

```

Ri$=EDIT$(1)
RO$=EDIT$(2)
Mat$=EDIT$(3)
Ri=VAL(Ri$)
RO=VAL(RO$)
Mat=VAL(Mat$)

*****error trap
IF (RO<=0) OR (Ri<=0) OR (Mat<=0) THEN GOSUB errortrap
IF (RO<=0) OR (Ri<=0) OR (Mat<=0) THEN RETURN
RETURN

getdata1:
Ri$=EDIT$(1)
RO$=EDIT$(2)
Mat$=EDIT$(3)
dep$=EDIT$(5)
AutoP$=EDIT$(4)
Ri=VAL(Ri$)
RO=VAL(RO$)
Mat=VAL(Mat$)
dep=VAL(dep$)
AutoP=VAL(AutoP$)
***** Set min depth of yielding
firstinterval=Ri+((RO-Ri)/Innerness)
IF dep > Ri AND dep < firstinterval THEN dep=firstinterval
*****error trap
IF (RO<=0) OR (Ri<=0) OR (Mat<=0) THEN GOSUB errortrap
IF (RO<=0) OR (Ri<=0) OR (Mat<=0) THEN RETURN
RETURN

getdata2:
ORI$=EDIT$(6)
ORO$=EDIT$(7)
OMat$=EDIT$(8)
poss$=EDIT$(9)
Oposs$=EDIT$(10)
ORI=VAL(ORI$)
ORO=VAL(ORO$)
OMat=VAL(OMat$)
poss=VAL(poss$)
Oposs=VAL(Oposs$)
*****error trap
IF (ORI>RO) OR (ORI<=0) THEN GOSUB errortrap
IF (ORI>RO) OR (ORI<=0) THEN RETURN
IF (ORO<RO) THEN GOSUB errortrap
IF (ORO<RO) THEN RETURN
IF OMat<=0 THEN GOSUB errortrap
IF OMat<=0 THEN RETURN
IF poss<=0 THEN GOSUB errortrap
IF poss<=0 THEN RETURN
IF Oposs<=0 THEN GOSUB errortrap

```

```

        IF Oposs<=0 THEN RETURN
RETURN

getdata3:
    designpress$=EDIT$(11)
    designpress=VAL(designpress$)
RETURN

getdata4:
    yieldbeg$=EDIT$(21)
    yieldfin$=EDIT$(22)
RETURN

'*****

'***** write user input data to a file *****
'*****

writedata:
presfile$="correct file type"
    IF filesave$="" THEN RETURN
    OPEN filesave$ FOR OUTPUT AS #1
    WRITE #1 ,presfile$
    GOSUB getdata1
    GOSUB getdata2
    GOSUB getdata3
    WRITE #1,Ri$,RO$,Mat$,dep$,AutoP$,ORIS$,OROS$,OMat$,poss$,Oposs$,
        designpress$
    CLOSE #1
RETURN

'*****

'***** Read user input data from a file *****
'*****

readdata:
presfile$="correct file type"
    IF fileopen$="" THEN RETURN
    OPEN fileopen$ FOR INPUT AS #1
    INPUT #1 ,presfile$
    IF presfile$="correct file type" THEN
        INPUT #1,Ri$,RO$,Mat$,dep$,AutoP$,ORIS$,OROS$,OMat$,poss$,Oposs$,
            DepPress$
        EDIT FIELD 1,Ri$,(ef1x1,ef1y1)-(ef1x2,ef1y2),2,2
        EDIT FIELD 2,RO$,(ef2x1,ef2y1)-(ef2x2,ef2y2),2,2
        EDIT FIELD 3,Mat$,(ef3x1,ef3y1)-(ef3x2,ef3y2),2,2
        EDIT FIELD 4,AutoP$,(ef4x1,ef4y1)-(ef4x2,ef4y2),2,2
        EDIT FIELD 5,dep$,(ef5x1,ef5y1)-(ef5x2,ef5y2),1,2
        EDIT FIELD 6,ORIS$,(ef6x1,ef6y1)-(ef6x2,ef6y2),2,2
        EDIT FIELD 7,OROS$,(ef7x1,ef7y1)-(ef7x2,ef7y2),2,2
        EDIT FIELD 8,OMat$,(ef8x1,ef8y1)-(ef8x2,ef8y2),2,2
        EDIT FIELD 9,poss$,(ef9x1,ef9y1)-(ef9x2,ef9y2),2,2
        EDIT FIELD 10,Oposs$,(ef10x1,ef10y1)-(ef10x2,ef10y2),2,2
    
```

```

        EDIT FIELD 11,DepPress$,(ef11x1,ef11y1)-(ef11x2,ef11y2),2,2
ELSE
    GOSUB fileerror
END IF
CLOSE #1
RETURN

'*****
'*****  make text file of stress arrays  *****
'*****
writetextreport:
    IF reportsave$="" THEN RETURN
    changecursor 4
    OPEN reportsave$ FOR OUTPUT AS #5
    arraytextfile=1
    GOSUB printstress
    arraytextfile=0
RETURN

'*****
'*****Print stress arrays *****
'*****
printerrortrap:
CALL INTCURSOR
RESUME errorleap
errorleap:
RETURN

printstress:
    ON ERROR GOTO printerrortrap
    IF arraytextfile=0 THEN
        OPEN "LPT1:prompt" FOR OUTPUT AS #5
        changecursor 4
        WINDOW OUTPUT #5
    END IF
    CALL TEXTFACE(1)
    CALL TEXTSIZE(14)
    PRINT #5,"Stress State Of Inner Cylinder With Autofrettage          Pressure
Applied"
    CALL TEXTFACE(0)
    CALL TEXTSIZE(12)
    PRINT #5,"          Node          Value of R          Radial          Stress
Hoop Stress"
    ON ERROR GOTO 0
    FOR i=1 TO innermeshplus
        PRINT #5, USING "#####.#          "; i, sigma(1,i),
sigma(2,i),sigma(3,i)
    NEXT i
    PRINT #5," "
    CALL TEXTFACE(1)

```

```

CALL TEXTSIZE(14)
PRINT #5,"Residual Stress State Of Inner Cylinder After          Autofrettage
Pressure"
CALL TEXTFACE(0)
CALL TEXTSIZE(12)
PRINT #5,"          Node          Value of R          Radial          Stress
Hoop Stress"
FOR i=1 TO innermeshplus
PRINT #5, USING "#####.#          ";i, Ressigma(1,i),
Ressigma(2,i),Ressigma(3,i)
NEXT i
PRINT #5," "
CALL TEXTFACE(1)
CALL TEXTSIZE(14)
PRINT #5,"          Stress State Of Inner Cylinder Due To          Shrinkfit
Only"
CALL TEXTFACE(0)
CALL TEXTSIZE(12)
PRINT #5,"          Node          Value of R          Radial          Stress
Hoop Stress"
FOR i=1 TO innermeshplus
PRINT #5, USING "#####.#          "; i,
shrksigma(1,i), shrksigma(2,i),shrksigma(3,i)
NEXT i
PRINT #5," "
CALL TEXTFACE(1)
CALL TEXTSIZE(14)
PRINT #5,"          Stress State Of Outer Cylinder Due To          Shrinkfit

PRINT #5,"          Also Residual Stress State Of Outer Cylinder          After
Shrinkfit"
CALL TEXTFACE(0)
CALL TEXTSIZE(12)
PRINT #5,"          Node          Value of R          Radial          Stress
Hoop Stress"
FOR i=1 TO outermeshplus
PRINT #5, USING "#####.#          "; i,
jshrksigma(1,i), jshrksigma(2,i),jshrksigma(3,i)
NEXT i
PRINT #5," "
CALL TEXTFACE(1)
CALL TEXTSIZE(14)
PRINT #5,"          Residual Stress State Of Inner Cylinder After          Shrinkfit"
CALL TEXTFACE(0)
CALL TEXTSIZE(12)
PRINT #5,"          Node          Value of R          Radial          Stress
Hoop Stress"
FOR i=1 TO innermeshplus
PRINT #5, USING "#####.#          ";i,
Resshrksigma(1,i), Resshrksigma(2,i),Resshrksigma(3,i)
NEXT i

```

```

PRINT #5," "
CALL TEXTFACE(1)
CALL TEXTSIZE(14)
PRINT #5,"Stress State Of Inner Cylinder Due To Operating      Pressure
Only"
CALL TEXTFACE(0)
CALL TEXTSIZE(12)
PRINT #5,"      Node      Value of R      Radial      Stress
Hoop Stress"
FOR i=1 TO innermeshplus
PRINT #5, USING "#####.#      ";i,
designsigma(1,i), designsigma(2,i),designsigma(3,i)
NEXT i
PRINT #5," "
CALL TEXTFACE(1)
CALL TEXTSIZE(14)
PRINT #5,"Stress State Of Outer Cylinder Due To Operating      Pressure
Only"
CALL TEXTFACE(0)
CALL TEXTSIZE(12)
PRINT #5,"      Node      Value of R      Radial      Stress
Hoop Stress"
FOR i=1 TO outermeshplus
PRINT #5, USING "#####.#      ";i,
jdesignsigma(1,i), jdesignsigma(2,i),jdesignsigma(3,i)
NEXT i
PRINT #5," "
CALL TEXTFACE(1)
CALL TEXTSIZE(14)
PRINT #5,"Total Stress State Of Inner Cylinder With      Operating
Pressure Applied"
CALL TEXTFACE(0)
CALL TEXTSIZE(12)
PRINT #5,"      Node      Value of R      Radial      Stress
Hoop Stress"
FOR i=1 TO innermeshplus
PRINT #5, USING "#####.#      ";i,
Resdesignsigma(1,i),
Resdesignsigma(2,i),Resdesignsigma(3,i)
NEXT i
PRINT #5," "
CALL TEXTFACE(1)
CALL TEXTSIZE(14)
PRINT #5,"Total Stress State Of Inner Cylinder With      Operating
Pressure Applied"
CALL TEXTFACE(0)
CALL TEXTSIZE(12)
PRINT #5,"      Node      Value of R      Radial      Stress
Hoop Stress"
FOR i=1 TO outermeshplus

```

```

        PRINT #5, USING "#####.#"          ";i,          jResdesignsigma(1,i),
jResdesignsigma(2,i),jResdesignsigma(3,i)
    NEXT i
    PRINT #5," "
    CLOSE #5
    CALL INITCURSOR
RETURN

```

```

'*****
** Writes text file of report          **
'*****

```

```

writereport:
    IF report$="" THEN RETURN
    changecursor 4
    OPEN report$ FOR OUTPUT AS #5
    GOSUB getdata1
    GOSUB getdata2
    GOSUB getdata3
    GOSUB getdata4
    writefileflag=1
    GOSUB printreport
    writefileflag=0
    CLOSE #5
    PICTURE ON:PICTURE OFF
    CALL INITCURSOR
RETURN

```

```

'*****
** Clears array memory when mesh is changed          **
'*****

```

```

undimension:
    ERASE sigma
    ERASE Unsigma
    ERASE Rcssigma
    ERASE shrksigma
    ERASE Rcsshrksigma
    ERASE jshrksigma
    ERASE x,y,Q,R
    ERASE plasticCriteria
    ERASE plasticCriteria2i
    ERASE plasticCriteria2j
    ERASE designsigma
    ERASE jdesignsigma
    ERASE Resdesignsigma
    ERASE jResdesignsigma
RETURN

```

```

'*****

```

```

***** examine stress arrays *****
'*****

examinestresses:
TIMER ON
    ssize%=maxmesh*10+15
    DIM s$(ssize%)
MENU OFF
top%=0
linenum%=0
s%=0
IF macsize$="small" THEN
    WINDOW 2,"Stress Values",(1,20)-(509,305),5
ELSE
    WINDOW 2,"Stress Values",(31,80)-(539,385),5
END IF
w%=WINDOW(2):h%=WINDOW(3)
SetRect scr%(0),0,-1,w%-15,h% 'scroll area
SetRect bar%(0),w%-15,-1,w%,h%+1 'scroll bar
NewScroll s&,bar%(0),1,1,1000,1 'create scroll bar
    retkey=0
    GOSUB loadSarray
TIMER OFF
CALL INITCURSOR
    WHILE (retkey<>1)
        ScrollText s&,scr%(0),s$(0),top%,ssize%,linenum%
        LET retkey=MOUSE(0)
    WEND
    DisposeScroll s&
WINDOW CLOSE 2
    GOSUB boxinScreen
MENU ON
    ERASE s$
RETURN
screenerrortrap:
RESUME screenerrorleap
'*****

```

```

'*****
***** Help screen *****
'*****

helpscreen:
DIM s2$(200)
MENU OFF
top%=0
linenum%=0
s%=0
IF macsize$="small" THEN
    WINDOW 2,"Help",(1,20)-(509,305),5
ELSE
    WINDOW 2,"Help",(31,80)-(539,385),5

```

```

END IF
w%=WINDOW(2):h%=WINDOW(3)
SetRect scr%(0),0,-1,w%-15,h%      'scroll area
SetRect bar%(0),w%-15,-1,w%,h%+1    'scroll bar
NewScroll s&,bar%(0),1,1,1000,1      'create scroll bar
    retkey=0
    GOSUB loadSarrayhelp
    WHILE (retkey<>1)
        ScrollText s&,scr%(0),s2$(0),top%,130,linenum%
        LET retkey=MOUSE(0)
    WEND
    DisposeScroll s&
WINDOW CLOSE 2
    GOSUB boxinScreen
    ERASE s2$
    MENU ON
RETURN

```

```

'*****

```

```

** load help screen      **

```

```

'*****

```

```

loadSarrayhelp:

```

```

    sloc=1
    s2$(sloc)="          *****"
    sloc=sloc+1
    s2$(sloc)="      ***   This Section of the Help Describes the       Available      ***"
    sloc=sloc+1
    s2$(sloc)="      ***                               Menu Selections                               * * *"
    sloc=sloc+1
    s2$(sloc)="          *****"
    sloc=sloc+1
    s2$(sloc)=" "
    sloc=sloc+1
    s2$(sloc)="Menus"
    sloc=sloc+1
    s2$(sloc)="File Menu"
    sloc=sloc+1
    s2$(sloc)="      Save Current Data"
    sloc=sloc+1
    s2$(sloc)="          Takes the current input data and saves it in a      text file."
    sloc=sloc+1
    s2$(sloc)="      Open Old Data"
    sloc=sloc+1
    s2$(sloc)="          Opens a previously created data file and loads      these"
    sloc=sloc+1
    s2$(sloc)="          values into the program."
    sloc=sloc+1
    s2$(sloc)="      Help"
    sloc=sloc+1
    s2$(sloc)="          Displays on line help."
    sloc=sloc+1

```

```

s2$(sloc)="      Quit"
sloc=sloc+1
s2$(sloc)="      Stops execution of program."
sloc=sloc+1
s2$(sloc)="Edit"
sloc=sloc+1
s2$(sloc)="      Save graph to clipboard"
sloc=sloc+1
s2$(sloc)="      Takes the current graph and pastes it onto the
      clipboard,"
sloc=sloc+1
s2$(sloc)="      for use in custom report generation."
sloc=sloc+1
s2$(sloc)="Report"
sloc=sloc+1
s2$(sloc)="      Print This Screen"
sloc=sloc+1
s2$(sloc)="      Sends the current screen to the printer."
sloc=sloc+1
s2$(sloc)="      Print report"
sloc=sloc+1
s2$(sloc)="      Sends a complete report including Input data
      graphs to the printer."
sloc=sloc+1
s2$(sloc)="      Write Text File of Stress Arrays"
sloc=sloc+1
s2$(sloc)="      Creates an ASCII text file of the stresses at
      each"
sloc=sloc+1
s2$(sloc)="      individual mesh point, with headings, for use in
      custom"
sloc=sloc+1
s2$(sloc)="      report generation."
sloc=sloc+1
s2$(sloc)="      Print Tabular Form of Stress Arrays"
sloc=sloc+1
s2$(sloc)="      Sends stresses at each individual mesh point
      with "
sloc=sloc+1
s2$(sloc)="      headings to the printer."
sloc=sloc+1
s2$(sloc)="      Examine Tabular Form of Stress Arrays"
sloc=sloc+1
s2$(sloc)="      Allows user to examine the stresses calculated
      at each"
sloc=sloc+1
s2$(sloc)="      individual mesh point in a scrollable window."
sloc=sloc+1
s2$(sloc)="      Create Report File"
sloc=sloc+1

```

```

s2$(sloc)="          Writes report to a text file for use in custom
    report"
sloc=sloc+1
s2$(sloc)="          generation."
sloc=sloc+1
s2$(sloc)=" "
sloc=sloc+1
s2$(sloc)="Yield Criteria"
sloc=sloc+1
s2$(sloc)="    Tresca"
sloc=sloc+1
s2$(sloc)="          Selects the Tresca yield criteria for use
    in the "
sloc=sloc+1
s2$(sloc)="          calculation of the stress state."
sloc=sloc+1
s2$(sloc)="    Von Mises"
sloc=sloc+1
s2$(sloc)="          Selects the Von Mises yield criteria for
    use in the "
sloc=sloc+1
s2$(sloc)="          calculation of the stress state."
sloc=sloc+1
s2$(sloc)=" "
sloc=sloc+1
s2$(sloc)="AutoP"
sloc=sloc+1
s2$(sloc)="    User Supplies Autofretage Pressure"
sloc=sloc+1
s2$(sloc)="          When this option is chosen the user
    must supply the"
sloc=sloc+1
s2$(sloc)="          autofretage pressure and the program
    will "
sloc=sloc+1
s2$(sloc)="          calculate the depth of yielding. "
sloc=sloc+1
s2$(sloc)="    User Supplies Depth of Yielding "
sloc=sloc+1
s2$(sloc)="          When this option is chosen the user
    must supply the "
sloc=sloc+1
s2$(sloc)="          depth of yielding and the program will
    calculate "
sloc=sloc+1
s2$(sloc)="          the autofretage pressure. "
sloc=sloc+1
s2$(sloc)="    Calculate Autofretage Pressure "
sloc=sloc+1
s2$(sloc)="          With this option the program will
    calculate the "

```

```

sloc=sloc+1
s2$(sloc)="          autofrettage pressure for a given
          depth of yielding "
sloc=sloc+1
s2$(sloc)="          without calculating the entire stress
          state in the "
sloc=sloc+1
s2$(sloc)="          pressure vessel. "
sloc=sloc+1
s2$(sloc)="          Calculate Pressure at Which Yielding Begins and "
sloc=sloc+1
s2$(sloc)="          Ends in the Cylinder "
sloc=sloc+1
s2$(sloc)="          This option calculates the pressure
          which plastic "
sloc=sloc+1
s2$(sloc)="          deformation will begin in the inner
          cylinder, and "
sloc=sloc+1
s2$(sloc)="          the pressure at which the inner
          cylinder will be "
sloc=sloc+1
s2$(sloc)="          completely plastic. "
sloc=sloc+1
s2$(sloc)="          Autofrettage Only"
sloc=sloc+1
s2$(sloc)="          This option should be selected when
          the user is "
sloc=sloc+1
s2$(sloc)="          interested in solving a single
          autofrettage "
sloc=sloc+1
s2$(sloc)="          only problem. "
sloc=sloc+1
s2$(sloc)="          Shrinkfit Only "
sloc=sloc+1
s2$(sloc)="          This option should be chosen when
          user is "
sloc=sloc+1
s2$(sloc)="          interested in solving a two cylinder,
          shrinkfit "
sloc=sloc+1
s2$(sloc)="          only problem. "
sloc=sloc+1
s2$(sloc)="          Shrinkfit and Autofrettage "
sloc=sloc+1
s2$(sloc)="          This option should be chosen when
          user is "
sloc=sloc+1
s2$(sloc)="          interested in solving a two cylinder
          autofrettage "

```

```

sloc=sloc+1
s2$(sloc)="                and shrinkfit problem.The program
    first calculates "
sloc=sloc+1
s2$(sloc)="                the stress state caused by the
    autofrettage of the                "
sloc=sloc+1
s2$(sloc)="                inner cylinder, and then                the
    stresses                "
sloc=sloc+1
s2$(sloc)="                caused by the shrinkfit of the outer
    cylinder and                "
sloc=sloc+1
s2$(sloc)="                that caused by the operating .
    "
sloc=sloc+1
s2$(sloc)="Stress "
sloc=sloc+1
s2$(sloc)="    Stress With Autofrettage Pressure(Inner
    Cylinder) "
sloc=sloc+1
s2$(sloc)="                Calculates the stress state of the
    inner cylinder                "
sloc=sloc+1
s2$(sloc)="                with the autofrettage pressure
    applied. "
sloc=sloc+1
s2$(sloc)="    Residual Stress After Autofrettage(Inner
    Cylinder) "
sloc=sloc+1
s2$(sloc)="                Calculates the residual stress state
    of the inner                "
sloc=sloc+1
s2$(sloc)="                cylinder after the autofrettage pressure    is
    "
sloc=sloc+1
s2$(sloc)="                released. "
sloc=sloc+1
s2$(sloc)="    Stress Due To Shrink Fit Only "
sloc=sloc+1
s2$(sloc)="                Calculates the stresses in both
    cylinders caused by                "
sloc=sloc+1
s2$(sloc)="                the shrinkfitting process. Does not
    include the                "
sloc=sloc+1
s2$(sloc)="                residual stresses from the
    autofrettage process. "
sloc=sloc+1
s2$(sloc)="    Total Stress After Shrink Fit "
sloc=sloc+1

```

```

s2$(sloc)="          Calculates the total stress state in
    both cylinders      "
sloc=sloc+1
s2$(sloc)="          after the shrinkfitting process.
    Includes the        "
sloc=sloc+1
s2$(sloc)="          stresses from the autofrettage
    process. "
sloc=sloc+1
s2$(sloc)="          Stress With Operating Pressure Only "
sloc=sloc+1
s2$(sloc)="          Calculates the stresses caused by      the
    application of      "
sloc=sloc+1
s2$(sloc)="          the operating pressure. Does not
    include the        "
sloc=sloc+1
s2$(sloc)="          residual stresses from the
    autofrettage process or "
sloc=sloc+1
s2$(sloc)="          the shrinkfitting process. "
sloc=sloc+1
s2$(sloc)="          Total Stress With Operating Pressure "
sloc=sloc+1
s2$(sloc)="          Calculates the total stress state in
    both cylinders      "
sloc=sloc+1
s2$(sloc)="          after the application of the      operating
    pressure.          "
sloc=sloc+1
s2$(sloc)="          Includes stresses from the
    autofrettage and    "
sloc=sloc+1
s2$(sloc)="          shrinkfitting processes. "
sloc=sloc+1
s2$(sloc)="Mesh "
sloc=sloc+1
s2$(sloc)="          Set Number of nodes "
sloc=sloc+1
s2$(sloc)="          The stresses in the cylinders are
    calculated at      "
sloc=sloc+1
s2$(sloc)="          discrete points in the cylinders. This
    option allows      "
sloc=sloc+1
s2$(sloc)="          the user to determine the number of
    nodes in the        "
sloc=sloc+1
s2$(sloc)="          inner and outer cylinders. Note: The
    error 'Out of      "
sloc=sloc+1

```

```

s2$(sloc)="          memory' will occur IF the number of
      nodes in the "
sloc=sloc+1
s2$(sloc)="          mesh is set to a large number. To correct
      this the          "
sloc=sloc+1
s2$(sloc)="          application memory size will need to be
      increased.          "
sloc=sloc+1
s2$(sloc)="          In order to do this, first quit the Under
      Pressure          "
sloc=sloc+1
s2$(sloc)="          application. Next select the Under
      Pressure          "
sloc=sloc+1
s2$(sloc)="          application by single clicking on its
      icon. Now          "
sloc=sloc+1
s2$(sloc)="          click the mouse in the box labeled
      application          "
sloc=sloc+1
s2$(sloc)="          memory size and increase the memory
      allotment.          "
sloc=sloc+1
s2$(sloc)="          Experimentation will determine the
      appropriate          "
sloc=sloc+1
s2$(sloc)="          amount of memory when running
      large numbers of          "
sloc=sloc+1
s2$(sloc)="          nodes.          "

```

RETURN

```

'*****
** Print current screen          **
'*****

PrintScreen:
changeursor 4
scale%=0
x%=0
y%=0
max&=1.3*(4+(SYSTEM(6)+1)*2*INT(SYSTEM(5)+16)/16)/4+1
IF max&>32767 OR max&*4+60 > FRE(0) THEN
  WINDOW 3,"",(10,106)-(509,338),3
  PRINT "Not Enough Memory in Program Data Block"
  PRINT ""
  INPUT "Press Return To Continue";AS
  WINDOW CLOSE 3
  RETURN
END IF

```

```

DIM PT%(1),screen&(max&)
LocalToGlobal PT%(0)
IF wholescreen=1 THEN
    GET (-PT%(1),-PT%(0))-(SYSTEM(5)-PT%(1),SYSTEM(6)-PT%(0)),screen&
ELSE
    GET (-2,-20)-(565,400),screen&      *** Get only under pressure window
END IF

    ON ERROR GOTO screenerrortrap
CALL INTCURSOR
OPEN "LPT1:prompt" FOR OUTPUT AS #10
changecursor 4
WINDOW OUTPUT #10
ON ERROR GOTO 0
IF scale% THEN
    PUT(0,0)-(x%,y%),screen&
ELSE
    PUT (0,0),screen&
END IF
CLOSE #10

    screenerrorleap:
ERASE PT%,screen&
CALL INTCURSOR
RETURN

' *****
** Load Text array for on screen examination **
' *****

loadSarray:
    sloc=1
    spacer$=" "
    spacer0$=" "
    spacer1$=" "
    s$(sloc)=" Stress State In Inner Cylinder With Autofrettage      Pressure Applied"
    sloc=sloc+1
    s$(sloc)=" Node      Value of R      Radial Stress      Hoop Stress"
    FOR i=1 TO innermeshplus
        IF i= 10 THEN spacer0$=" "
        IF i= 100 THEN spacer0$=""
        sloc=sloc+1
        sigmaT$=LEFT$((STR$(sigma(1,i))),5)
        LengthS2=LEN(STR$(sigma(1,i)))
        GOSUB spacermaker2
        LengthS3=LEN(STR$(sigma(2,i)))
        GOSUB spacermaker3
        s$(sloc)=          spacer0$+STR$(i)+spacer1$+sigmaT$+spacer2$+STR$(sigma(2
        , i      ))+spacer3$+STR$(sigma(3,i))
    NEXT i
    spacer0$=" "
    sloc=sloc+1
    s$(sloc)=" "
    sloc=sloc+1

```

```

s$(sloc)="      Residual Stress State In The Inner Cylinder After      The Autofrettage"
sloc=sloc+1
s$(sloc)="                                Pressure Is Released"
sloc=sloc+1
s$(sloc)=" Node      Value of R                                Radial Stress                                Hoop Stress"
FOR i=1 TO innermeshplus
  IF i= 10 THEN spacer0$=" "
  IF i= 100 THEN spacer0$=""
  sloc=sloc+1
  sigmaT$=LEFT$((STR$(Ressigma(1,i))),5)
  LengthS2=LEN(STR$(Ressigma(1,i)))
  GOSUB spacemaker2
  LengthS3=LEN(STR$(Ressigma(2,i)))
  GOSUB spacemaker3
  s$(sloc)=
  spacer0$+STR$(i)+spacer1$+sigmaT$+spacer2$+STR$(Ressigm      a
  (2,i))+spacer3$+STR$(Ressigma(3,i))
NEXT i
  spacer0$=" "
  sloc=sloc+1
  s$(sloc)=" "
  sloc=sloc+1
  s$(sloc)="      Stress State In The Inner Cylinder Caused By      The Shrink Fit"
  sloc=sloc+1
s$(sloc)=" Node      Value of R                                Radial Stress                                Hoop Stress"
FOR i=1 TO innermeshplus
  IF i= 10 THEN spacer0$=" "
  IF i= 100 THEN spacer0$=""
  sigmaT$=LEFT$((STR$(shrksigma(1,i))),5)
  LengthS2=LEN(STR$(shrksigma(1,i)))
  GOSUB spacemaker2
  LengthS3=LEN(STR$(shrksigma(2,i)))
  GOSUB spacemaker3
  sloc=sloc+1
  s$(sloc)=      spacer0$+STR$(i)+spacer1$+sigmaT$+spacer2$+STR$(shrksig
  m      a(2,i))+spacer3$+STR$(shrksigma(3,i))
NEXT i
  spacer0$=" "
  sloc=sloc+1
  s$(sloc)=" "
  sloc=sloc+1
  s$(sloc)="      Total Residual Stress State In The Outer Cylinder      After The Shrink Fit"
  sloc=sloc+1
s$(sloc)=" Node      Value of R                                Radial Stress                                Hoop Stress"
FOR i=1 TO outermeshplus
  IF i= 10 THEN spacer0$=" "
  IF i= 100 THEN spacer0$=""
  sigmaT$=LEFT$((STR$(jshrksigma(1,i))),5)
  LengthS2=LEN(STR$(jshrksigma(1,i)))
  GOSUB spacemaker2
  LengthS3=LEN(STR$(jshrksigma(2,i)))

```

```

      GOSUB spacemaker3
      sloc=sloc+1
      s$(sloc)=      spacer0$+STR$(i)+spacer1$+sigmaT$+spacer2$+STR$(jshrksig
ma(2,i))+spacer3$+STR$(jshrksigma(3,i))
NEXT i
      spacer0$=" "
      sloc=sloc+1
      s$(sloc)=" "
      sloc=sloc+1
      s$(sloc)="      Total Residual Stress State In The Inner      Cylinder After The Shrink Fit"
      sloc=sloc+1
      s$(sloc)=" Node      Value of R      Radial Stress      Hoop Stress"
      FOR i=1 TO innermeshplus
        IF i= 10 THEN spacer0$=" "
        IF i= 100 THEN spacer0$=""
        sigmaT$=LEFT$((STR$(Resshrksigma(1,i))),5)
        LengthS2=LEN(STR$(Resshrksigma(1,i)))
        GOSUB spacemaker2
        LengthS3=LEN(STR$(Resshrksigma(2,i)))
        GOSUB spacemaker3
        sloc=sloc+1
        s$(sloc)=
      spacer0$+STR$(i)+spacer1$+sigmaT$+spacer2$+STR$(Resshrks
igma(2,i))+spacer3$+STR$(Resshrksigma(3,i))
NEXT i
      spacer0$=" "
      sloc=sloc+1
      s$(sloc)=" "
      sloc=sloc+1
      s$(sloc)="      Stress State Caused By The Application Of The      Operating Pressure
Only"
      sloc=sloc+1
      s$(sloc)="      In The Inner Cylinder"
      sloc=sloc+1
      s$(sloc)=" Node      Value of R      Radial Stress      Hoop Stress"
      FOR i=1 TO innermeshplus
        IF i= 10 THEN spacer0$=" "
        IF i= 100 THEN spacer0$=""
        sigmaT$=LEFT$((STR$(designsigma(1,i))),5)
        LengthS2=LEN(STR$(designsigma(1,i)))
        GOSUB spacemaker2
        LengthS3=LEN(STR$(designsigma(2,i)))
        GOSUB spacemaker3
        sloc=sloc+1
        s$(sloc)=      spacer0$+STR$(i)+spacer1$+sigmaT$+spacer2$+STR$(designsi
g      ma(2,i))+spacer3$+STR$(designsigma(3,i))
NEXT i
      spacer0$=" "
      sloc=sloc+1
      s$(sloc)=" "
      sloc=sloc+1

```

```

s$(sloc)="      Stress State Caused By The Application Of The      Operating Pressure
Only"
sloc=sloc+1
s$(sloc)="                                In The Outer Cylinder"
sloc=sloc+1
s$(sloc)=" Node      Value of R                                Radial Stress                                Hoop Stress"
FOR i=1 TO outermeshplus
  IF i= 10 THEN spacer0$=" "
  IF i= 100 THEN spacer0$=""
  sigmaT$=LEFT$((STR$(jdesignsigma(1,i))),5)
  LengthS2=LEN(STR$(jdesignsigma(1,i)))
  GOSUB spacemaker2
  LengthS3=LEN(STR$(jdesignsigma(2,i)))
  GOSUB spacemaker3
  sloc=sloc+1
  s$(sloc)=      spacer0$+STR$(i)+spacer1$+sigmaT$+spacer2$+STR$(jdesign
si      gma(2,i))+spacer3$+STR$(jdesignsigma(3,i))
NEXT i
  spacer0$=" "
  sloc=sloc+1
  s$(sloc)="      "
  sloc=sloc+1
  s$(sloc)="      Total Stress State In Inner Cylinder With The      Operating Pressure
Applied"
  sloc=sloc+1
s$(sloc)=" Node      Value of R                                Radial Stress                                Hoop Stress"
FOR i=1 TO innermeshplus
  IF i= 10 THEN spacer0$=" "
  IF i= 100 THEN spacer0$=""
  sigmaT$=LEFT$((STR$(Resdesignsigma(1,i))),5)
  LengthS2=LEN(STR$(Resdesignsigma(1,i)))
  GOSUB spacemaker2
  LengthS3=LEN(STR$(Resdesignsigma(2,i)))
  GOSUB spacemaker3
  sloc=sloc+1
  s$(sloc)=      spacer0$+STR$(i)+spacer1$+sigmaT$+spacer2$+STR$(Resdesi
g      nsigma(2,i))+spacer3$+STR$(Resdesignsigma(3,i))
NEXT i
  spacer0$=" "
  sloc=sloc+1
  s$(sloc)="      "
  sloc=sloc+1
  s$(sloc)="      Total Stress State In The Outer Cylinder With      Operating Pressure
Applied"
  sloc=sloc+1
s$(sloc)=" Node      Value of R                                Radial Stress                                Hoop Stress"
FOR i=1 TO outermeshplus
  IF i= 10 THEN spacer0$=" "
  IF i= 100 THEN spacer0$=""
  sigmaT$=LEFT$((STR$(jResdesignsigma(1,i))),5)
  LengthS2=LEN(STR$(jResdesignsigma(1,i)))

```

```

        GOSUB spacemaker2
        LengthS3=LEN(STR$(jResdesignsigma(2,i)))
        GOSUB spacemaker3
        sloc=sloc+1
        s$(sloc)=      spacer0$+STR$(i)+spacer1$+sigmaT$+spacer2$+STR$(jResdes
        i      gnsigma(2,i))+spacer3$+STR$(jResdesignsigma(3,i))
    NEXT i
    TIMER OFF
    CALL INITCURSOR
RETURN

```

```

'*****
** Makes spacers for aligned stress array text      **
'*****

```

```

spacemaker2:
    SpacerLength=35-LengthS2
    spacer2$=""
    FOR k=1 TO SpacerLength
        spacer2$=spacer2$ + " "
    NEXT k
RETURN

```

```

spacemaker3:
    SpacerLength=35-LengthS3
    spacer3$=""
    FOR k=1 TO SpacerLength
        spacer3$=spacer3$ + " "
    NEXT k
RETURN

```

```

'*****
** Refresh graphs when overwritten      **
'*****

```

```

refresh: 'refresh graph
forecolor 33
    start=TIMER
    IF (start-lasttime)<4 THEN RETURN
    action=0
    IF refreshflag=0 THEN
        GOSUB boxinScreen
    END IF
    IF refreshflag=1 THEN
        GOSUB graphwithpres
    END IF
    IF refreshflag=2 THEN
        GOSUB resautograph
    END IF
    IF refreshflag=3 THEN
        GOSUB shrinkprnt
    END IF

```

```

END IF
  IF refreshflag=4 THEN
    GOSUB resshrinkprnt
  END IF
  IF refreshflag=5 THEN
    IF problemtype$<>"Autofrettagage only" THEN
      GOSUB designPrnt
    ELSE
      GOSUB designAutoPrnt
    END IF
  END IF
  IF refreshflag=6 THEN
    IF problemtype$="Autofrettagage only" THEN
      GOSUB AresdesignPrnt
    ELSE
      GOSUB rcsdesignPrnt
    END IF
  END IF
  lasttime=TIMER
  EDIT FIELD 227," ",(700,700)-(720,720),3,1
RETURN

```

deactivateMenus:

```

  MENU 1,0,0
  MENU 2,0,0
  MENU 3,0,0
  MENU 4,0,0
  MENU 5,0,0
  MENU 6,0,0
  MENU 7,0,0
  MENU 8,0,0
RETURN

```

activateMenus:

```

  MENU 1,0,1
  MENU 2,0,1
  MENU 3,0,1
  MENU 4,0,1
  MENU 5,0,1
  MENU 6,0,1
  MENU 7,0,1
  MENU 8,0,1
RETURN

```

```

  printREPerrotrap:
CALL INITCURSOR
RESUME errorleap2
  errorleap2:
ON ERROR GOTO 0

```

RETURN

** send report to printer **

printreport:

IF writefileflag=0 THEN

ON ERROR GOTO printRErrortrap

CALL INITCURSOR

OPEN "LPT1:prompt" FOR OUTPUT AS #5

changecursor 4

cleargraphflag=1

graphtitleflag=1

END IF

IF problemtype\$="Autofrettage only" THEN

GOSUB desmaxloc

IF (goesplasticUnload=1)THEN

bschStr\$=" A correction due to the Baushinger
was used"

effect

bschStr2\$=" in the calculation of the stresses
by the"

caused

bschStr3\$=" release of the autofrettage pressure."

ELSE

bschStr\$=" Linear unloading was assumed in the
calculation"

bschStr2\$=" of the stresses caused by the release of

the"

bschStr3\$=" autofrettage pressure."

END IF

prnt=VAL(Reyielding\$)

prnt0=FIX(prnt)

prnt=VAL(yieldbeg\$)

prnt1=FIX(prnt)

prnt=VAL(yieldfin\$)

prnt2=FIX(prnt)

prnt=VAL(AutoP\$)

prnt3=FIX(prnt)

prnt=VAL(DepPress\$)

prnt4=FIX(prnt)

prnt5=FIX(sigma(2,1))

prnt6=FIX(sigma(3,1))

prnt7=FIX(sigma(2,innermeshplus))

prnt8=FIX(sigma(3,innermeshplus))

prnt9=FIX(sigma(2,maxlocationR))

prnt10=FIX(sigma(3,maxlocationT))

prnt11=FIX(Ressigma(2,1))

prnt12=FIX(Ressigma(3,1))

prnt13=FIX(Ressigma(2,innermeshplus))

prnt14=FIX(Ressigma(3,innermeshplus))

prnt15=FIX(Ressigma(2,maxlocationRares))

prnt16=FIX(Ressigma(3,maxlocationTares))

```

prnt17=FIX(designsigma(2,1))
prnt18=FIX(designsigma(3,1))
prnt19=FIX(designsigma(2,innermeshplus))
prnt20=FIX(designsigma(3,innermeshplus))
prnt21=FIX(designsigma(2,maxlocationAdeR))
prnt22=FIX(designsigma(3,maxlocationAdeT))
prnt23=FIX(Resdesignsigma(2,1))
prnt24=FIX(Resdesignsigma(3,1))
prnt25=FIX(Resdesignsigma(2,innermeshplus))
prnt26=FIX(Resdesignsigma(3,innermeshplus))
prnt27=FIX(Resdesignsigma(2,maxlocationAAdeR))
prnt28=FIX(Resdesignsigma(3,maxlocationAAdeT))

```

```

FOR i=1 TO 3
  PRINT #5," "
NEXT i
IF writefileflag=0 THEN WINDOW OUTPUT #5
CALL TEXTFACE(1)
CALL TEXTSIZE(14)
PRINT #5,"                               Stress Analysis Report"
PRINT #5," "
CALL TEXTSIZE(12)
PRINT #5,"Stress Analysis For Autofretage and Operating      Pressure of a
Single Cylinder"
ON ERROR GOTO 0
CALL TEXTFACE(0)
PRINT #5," "
PRINT #5,"      Inner Radius of Inner Cylinder =
";Ri$;LengthUnit$
PRINT #5,"      Outer Radius of Inner Cylinder =
";RO$;LengthUnit$
PRINT #5,"      Yield Stress in Tension of Inner Cylinder =
";Mat$;PresUnit$
PRINT #5,"      Poisson's Ratio of Inner Cylinder = ";poss$
PRINT #5,"      Pressure at Which Yielding Begins at the      Bore of Inner
Cylinder = ";prnt1;PresUnit$
PRINT #5,"      Pressure at Which the Inner Cylinder is      Completely
Yielded = ";prnt2;PresUnit$
PRINT #5,"      Autofretage Pressure = ";prnt3;PresUnit$
PRINT #5,"      Depth of Yielding Caused by the Autofretage      Pressure =
";dep$;LengthUnit$
PRINT #5,"      Operating Pressure = ";prnt4;PresUnit$
PRINT #5,"      Pressure at Which Reyielding Will Occur at      the Bore =
";prnt0;PresUnit$
PRINT #5,"      Factor of Safety = ";Factor$
PRINT #5," "
PRINT #5,bachStr$
PRINT #5,bachStr2$
PRINT #5,bachStr3$

```

```

PRINT #5," "
CALL TEXTFACE(1)
PRINT #5,"Stresses With the Autofrettage Pressure
Applied "
CALL TEXTFACE(0)
PRINT #5," "
PRINT #5," Radial stress at the bore = ";prnt5;PresUnit$
PRINT #5," Hoop stress at the bore = ";prnt6;PresUnit$
PRINT #5," Radial stress at the outer surface =
";prnt7;PresUnit$
PRINT #5," Hoop stress at the outer surface =
";prnt8;PresUnit$
PRINT #5," Maximum radial stress = ";prnt9;PresUnit$;" at
R=";(sigma(1,maxlocationR));LengthUnit$
PRINT #5," Maximum hoop stress = ";prnt10;PresUnit$;" at
R=";(sigma(1,maxlocationT));LengthUnit$
PRINT #5," "
PRINT #5," "
CALL TEXTFACE(1)
PRINT #5,"Residual Stresses After the Autofrettage
Released "
CALL TEXTFACE(0)
PRINT #5," "
PRINT #5," Radial stress at the bore =
";prnt11;PresUnit$
PRINT #5," Hoop stress at the bore = ";prnt12;PresUnit$
PRINT #5," Radial stress at the outer surface =
";prnt13;PresUnit$
PRINT #5," Hoop stress at the outer surface =
";prnt14;PresUnit$
PRINT #5," Maximum radial stress =
";prnt15;PresUnit$;" at
R=";(Ressigma(1,maxlocationRares));LengthUnit$
PRINT #5," Maximum hoop stress = ";prnt16;PresUnit$;" at
R=";(Ressigma(1,maxlocationTares));LengthUnit$
PRINT #5," "
PRINT #5," "
PRINT #5,"
page 1 of 3"
FOR i=1 TO 3
PRINT #5," "
NEXT i
CALL TEXTFACE(1)
PRINT #5,"Stresses Caused by Operating Pressure on
Configuration"
CALL TEXTFACE(0)
PRINT #5," "
PRINT #5," Radial stress at the bore =
";prnt17;PresUnit$
PRINT #5," Hoop stress at the bore = ";prnt18;PresUnit$

```

```

        PRINT #5,"    Radial stress at the outer surface =
";prnt19;PresUnit$
        PRINT #5,"    Hoop stress at the outer surface =
";prnt20;PresUnit$
        PRINT #5,"    Maximum radial stress =
";prnt21;PresUnit$;"    at
R=";(designsigma(1,maxlocationAdeR));LengthUnit$
        PRINT #5,"    Maximum hoop stress = ";prnt22;PresUnit$;"    at
R=";(designsigma(1,maxlocationAdeT));LengthUnit$
        PRINT #5," "
        PRINT #5," "
CALL TEXTFACE(1)
        PRINT #5,"Total Stress State With Operating Pressure    Applied "
CALL TEXTFACE(0)
        PRINT #5," "
        PRINT #5,"    Radial stress at the bore =
";prnt23;PresUnit$
        PRINT #5,"    Hoop stress at the bore = ";prnt24;PresUnit$
        PRINT #5,"    Radial stress at the outer surface =
";prnt25;PresUnit$
        PRINT #5,"    Hoop stress at the outer surface =
";prnt26;PresUnit$
        PRINT #5,"    Maximum radial stress = ";prnt27;PresUnit$;"    at

R=";(Resdesignsigma(2,maxlocationAAdeR));LengthUnit$
        PRINT #5,"    Maximum hoop stress = ";prnt28;PresUnit$;"    at

R=";(Resdesignsigma(3,maxlocationAAdeT));LengthUnit$
        PRINT #5," "
        PRINT #5," "
        FOR i=1 TO 21
            PRINT #5," "
        NEXT i
        PRINT #5,"
        page 2 of 3"
        FOR i=1 TO 29
            PRINT #5," "
        NEXT i
IF writeflagfile=0 THEN
        WINDOW 4,"printing window",(0,0)-(630,740),1
        WINDOW OUTPUT 4
        CALL TEXTFACE(1)
        EDIT FIELD 222,"Now Printing Report, Please
Wait",(50,200)-(450,220),7,2
        CALL TEXTFACE(0)

        PICTURE ON
        yoriginlocation=130
        GOSUB SetGraphLocation
        GOSUB resautograph
        PICTURE OFF

```

```

    graphic1$=PICTURES
    PICTURE ON:PICTURE OFF

    yoriginlocation=360
    GOSUB SetGraphLocation
    PICTURE ON
    GOSUB designAutoPrnt
    PICTURE OFF
    graphic2$=PICTURES
    PICTURE ON:PICTURE OFF

    yoriginlocation=590
    GOSUB SetGraphLocation
    PICTURE ON
    GOSUB AresdesignPrnt
    EDIT FIELD 53,"page 3 of 3",(460,690)-(540,706),3,2
    EDIT FIELD 247," ",(2000,2000)-(2020,2020),3,2
    PICTURE OFF
    graphic3$=PICTURES
    PICTURE ON:PICTURE OFF
    WINDOW OUTPUT #5
    PICTURE, graphic1$
    PICTURE, graphic2$
    PICTURE, graphic3$
END IF
END IF
IF problemtype$="Shrinkfit only" THEN
    GOSUB maxstressOPO
    GOSUB maxstressROP
    prnt=VAL(Reyielding$)
    prnt50=FIX(prnt)
    prnt=VAL(yieldbeg$)
    prnt51=FIX(prnt)
    prnt=VAL(yieldfin$)
    prnt52=FIX(prnt)
    prnt=VAL(AutoP$)
    prnt53=FIX(prnt)
    prnt=VAL(DepPress$)
    prnt54=FIX(prnt)
    prnt=VAL(Ipres$)
    prnt55=FIX(prnt)

    FOR i=1 TO 3
        PRINT #5," "
    NEXT i
    IF writefileflag=0 THEN WINDOW OUTPUT #5
    CALL TEXTFACE(1)
    CALL TEXTSIZE(14)
    PRINT #5,"
    PRINT #5," "
    CALL TEXTSIZE(12)

```

Stress Analysis Report"

```

PRINT #5,"Stress Analysis for Shrinkfit and Operating
Two Cylinders"
ON ERROR GOTO 0
CALL TEXTFACE(0)
PRINT #5," "
PRINT #5," Inner Radius of Inner Cylinder =
";Ri$;LengthUnit$
PRINT #5," Outer Radius of Inner Cylinder =
";RO$;LengthUnit$
PRINT #5," Inner Radius of Outer Cylinder =
";ORi$;LengthUnit$
PRINT #5," Outer Radius of Outer Cylinder =
";ORo$;LengthUnit$
PRINT #5," Yield Stress in Tension of Inner Cylinder =
";Mat$;PresUnit$
PRINT #5," Yield Stress in Tension of Outer Cylinder =
";OMat$;PresUnit$
PRINT #5," Poisson's Ratio of Inner Cylinder = ";poss$
PRINT #5," Poisson's Ratio of Outer Cylinder = ";Oposs$
PRINT #5," Pressure at Which Yielding Begins at the
Cylinder= ";prnt51;PresUnit$
PRINT #5," Pressure at Which the Inner Cylinder is
Yielded = ";prnt52;PresUnit$
PRINT #5," Autofrettage Pressure= ";prnt53;PresUnit$
PRINT #5," Depth of Yielding Caused by the
Autofrettage Pressure= ";dep$;LengthUnit$
PRINT #5," Operating Pressure= ";prnt54;PresUnit$
PRINT #5," Interface Pressure Between the Cylinders
Shrinkfit= ";prnt55;PresUnit$
PRINT #5," Pressure at Which Yielding Will Occur at
Bore = ";prnt50;PresUnit$
PRINT #5," Factor of Safety = ";Factor$
PRINT #5," "
PRINT #5," "
CALL TEXTFACE(1)
PRINT #5,"Residual Stress State After Shrinkfit "
PRINT #5," "
PRINT #5," Stresses in the Inner Cylinder "
PRINT #5," "
CALL TEXTFACE(0)
PRINT #5," Radial stress at the bore =
";FIX(Resshrksigma(2,1));PresUnit$
PRINT #5," Hoop stress at the bore =
";FIX(Resshrksigma(3,1));PresUnit$
PRINT #5," Radial stress at the outer surface =
";FIX(Resshrksigma(2,innermeshplus));PresUnit$
PRINT #5," Hoop stress at the outer surface =
";FIX(Resshrksigma(3,innermeshplus));PresUnit$
PRINT #5," Maximum radial stress =
";FIX(Resshrksigma(2,maxlocationRres));PresUnit$;" at
R=";(Resshrksigma(1,maxlocationRres));LengthUnit$

```

Pressure of

Bore of Inner

Completely

Caused by the

the

```

        PRINT #5,"    Maximum hoop stress =
";FIX(Resshrksigma(3,maxlocationTsres));PresUnit$;"    at
R=";(Resshrksigma(1,maxlocationTsres));LengthUnit$
        PRINT #5," "
        CALL TEXTFACE(1)
        PRINT #5," Stresses in Outer Cylinder "
        CALL TEXTFACE(0)
        PRINT #5," "
        PRINT #5,"    Radial stress at the bore =
";FIX(jshrksigma(2,1));PresUnit$
        PRINT #5,"    Hoop stress at the bore =
";FIX(jshrksigma(3,1));PresUnit$
        PRINT #5,"    Radial stress at the outer surface =
";FIX(jshrksigma(2,outermeshplus));PresUnit$
        PRINT #5,"    Hoop stress at the outer surface =
";FIX(jshrksigma(3,outermeshplus));PresUnit$
        PRINT #5,"    Maximum radial stress =
";FIX(jshrksigma(2,OmaxlocationRsres));PresUnit$;"    at
R=";(jshrksigma(1,OmaxlocationRsres));LengthUnit$
        PRINT #5,"    Maximum hoop stress =
";FIX(jshrksigma(3,OmaxlocationTsres));PresUnit$;"    at
R=";(jshrksigma(1,OmaxlocationTsres));LengthUnit$
        PRINT #5,"
        page 1 of 3"
        FOR i=1 TO 2
        PRINT #5," "
        NEXT i
        CALL TEXTFACE(1)
        PRINT #5,"Stresses Caused by Operating Pressure Only"
        PRINT #5," "
        PRINT #5," Stresses in the Inner Cylinder "
        CALL TEXTFACE(0)
        PRINT #5," "
        PRINT #5,"    Radial stress at the bore =
";FIX(designsigma(2,1));PresUnit$
        PRINT #5,"    Hoop stress at the bore =
";FIX(designsigma(3,1));PresUnit$
        PRINT #5,"    Radial stress at the outer surface =
";FIX(designsigma(2,innermeshplus));PresUnit$
        PRINT #5,"    Hoop stress at the outer surface =
";FIX(designsigma(3,innermeshplus));PresUnit$
        PRINT #5,"    Maximum radial stress =
";FIX(designsigma(2,ImaxRdoLoc));PresUnit$;"    at
R=";(designsigma(1,ImaxRdoLoc));LengthUnit$
        PRINT #5,"    Maximum hoop stress =
";FIX(designsigma(3,ImaxTdoLoc));PresUnit$;"    at
R=";(designsigma(1,ImaxTdoLoc));LengthUnit$
        PRINT #5," "
        PRINT #5," "
        CALL TEXTFACE(1)
        PRINT #5," Stresses in the Outer Cylinder "

```

```

CALL TEXTFACE(0)
PRINT #5," "
    PRINT #5,"    Radial stress at the bore =
";FIX(jdesignsigma(2,1));PresUnit$
    PRINT #5,"    Hoop stress at the bore =
";FIX(jdesignsigma(3,1));PresUnit$
    PRINT #5,"    Radial stress at the outer surface =
";FIX(jdesignsigma(2,outermeshplus));PresUnit$
    PRINT #5,"    Hoop stress at the outer surface =
";FIX(jdesignsigma(3,outermeshplus));PresUnit$
    PRINT #5,"    Maximum radial stress =
";FIX(jdesignsigma(2,OmaxRdoLoc));PresUnit$;"    at
R=";(jdesignsigma(1,OmaxRdoLoc));LengthUnit$
    PRINT #5,"    Maximum hoop stress =
";FIX(jdesignsigma(3,OmaxTdoLoc));PresUnit$;"    at
R=";(jdesignsigma(1,OmaxTdoLoc));LengthUnit$
PRINT #5," "
PRINT #5," "

CALL TEXTFACE(1)
    PRINT #5,"Total Stress State With Operating Pressure
PRINT #5," "
    PRINT #5," Stresses in the Inner Cylinder "
CALL TEXTFACE(0)
    PRINT #5," "
    PRINT #5,"    Radial stress at the bore =
";FIX(Resdesignsigma(2,1));PresUnit$
    PRINT #5,"    Hoop stress at the bore =
";FIX(Resdesignsigma(3,1));PresUnit$
    PRINT #5,"    Radial stress at the outer surface =
";FIX(Resdesignsigma(2,innermeshplus));PresUnit$
    PRINT #5,"    Hoop stress at the outer surface =
";FIX(Resdesignsigma(3,innermeshplus));PresUnit$
    PRINT #5,"    Maximum radial stress =
";FIX(Resdesignsigma(2,ImaxRL));PresUnit$;"    at
R=";(Resdesignsigma(1,ImaxRL));LengthUnit$
    PRINT #5,"    Maximum hoop stress =
";FIX(Resdesignsigma(3,ImaxTL));PresUnit$;"    at
R=";(Resdesignsigma(1,ImaxTL));LengthUnit$
PRINT #5," "
PRINT #5," "
CALL TEXTFACE(1)
    PRINT #5," Stresses in the Outer Cylinder "
CALL TEXTFACE(0)
    PRINT #5," "
    PRINT #5,"    Radial stress at the bore =
";FIX(jResdesignsigma(2,1));PresUnit$
    PRINT #5,"    Hoop stress at the bore =
";FIX(jResdesignsigma(3,1));PresUnit$
    PRINT #5,"    Radial stress at the outer surface =
";FIX(jResdesignsigma(2,outermeshplus));PresUnit$

```

Applied "

```

PRINT #5,"    Hoop stress at the outer surface =
";FIX(jResdesignsigma(3,outermeshplus));PresUnit$
PRINT #5,"    Maximum radial stress =
";FIX(jResdesignsigma(2,OmaxRL));PresUnit$;"    at
R=";(jResdesignsigma(1,OmaxRL));LengthUnit$
PRINT #5,"    Maximum hoop stress =
";FIX(jResdesignsigma(3,OmaxTL));PresUnit$;"    at
R=";(jResdesignsigma(1,OmaxTL));LengthUnit$
PRINT #5,"

```

page 2 of 3"

```
FOR i=1 TO 10
```

```
PRINT #5," "
```

```
NEXT i
```

```
IF writefileflag=0 THEN
```

```
WINDOW 4,"Printing Window",(0,0)-(630,740),1
```

```
WINDOW OUTPUT 4
```

```
CALL TEXTFACE(1)
```

```
EDIT FIELD 222,"Now Printing Report, Please
Wait",(50,200)-(450,220),7,2
```

```
CALL TEXTFACE(0)
```

```
PICTURE ON
```

```
yoriginlocation=130
```

```
GOSUB SetGraphLocation
```

```
GOSUB shrinkprnt
```

```
PICTURE OFF
```

```
graphic1$=PICTURES
```

```
PICTURE ON:PICTURE OFF
```

```
yoriginlocation=360
```

```
GOSUB SetGraphLocation
```

```
PICTURE ON
```

```
GOSUB designPrnt
```

```
PICTURE OFF
```

```
graphic2$=PICTURES
```

```
PICTURE ON:PICTURE OFF
```

```
yoriginlocation=590
```

```
GOSUB SetGraphLocation
```

```
PICTURE ON
```

```
GOSUB redesignPrnt
```

```
EDIT FIELD 53,"page 3 of 3",(460,690)-(540,706),3,2
```

```
EDIT FIELD 247," ",(2000,2000)-(2020,2020),3,2
```

```
PICTURE OFF
```

```
graphic3$=PICTURES
```

```
PICTURE ON:PICTURE OFF
```

```
WINDOW OUTPUT #5
```

```
PICTURE, graphic1$
```

```
PICTURE, graphic2$
```

```
PICTURE, graphic3$
```

```
END IF
```

```

END IF
IF problemtype$="Both" THEN
  GOSUB maxstressjshrk
  GOSUB maxstressRS
  GOSUB maxstressOPO
  GOSUB maxstressROP
  IF (goesplasticUnload=1)THEN
    bschStr$="      A correction due to the Baushinger
effect      was used"
    bschStr2$="      in the calculation of the stresses
caused      by the"
    bschStr3$="      release of the autofrettage pressure."
  ELSE
    bschStr$="      Linear unloading was assumed in the
calculation"
    bschStr2$="      of the stresses caused by the release of      the"
    bschStr3$="      autofrettage pressure."
  END IF

  PRINT #5," "
  IF writefileflag=0 THEN WINDOW OUTPUT #5
  CALL TEXTFACE(1)
  CALL TEXTSIZE(14)
  PRINT #5,"                      Stress Analysis Report"
  PRINT #5," "
  CALL TEXTSIZE(12)
  PRINT #5,"Stress Analysis for Autofrettage, Shrinkfit and      Operating
      Pressure"
  PRINT #5,"                      of Two Cylinders"
ON ERROR GOTO 0
  CALL TEXTFACE(0)
  prnt=VAL(Reyielding$)
  prnt50=FIX(prnt)
  prnt=VAL(yieldbeg$)
  prnt51=FIX(prnt)
  prnt=VAL(yieldfin$)
  prnt52=FIX(prnt)
  prnt=VAL(AutoP$)
  prnt53=FIX(prnt)
  prnt=VAL(DepPress$)
  prnt54=FIX(prnt)
  prnt=VAL(Ipres$)
  prnt55=FIX(prnt)
  PRINT #5," "
  PRINT #5,"      Inner Radius of Inner Cylinder =
";Ri$;LengthUnit$
  PRINT #5,"      Outer Radius of Inner Cylinder =
";RO$;LengthUnit$
  PRINT #5,"      Inner Radius of Outer Cylinder =
";ORIS$;LengthUnit$

```

```

PRINT #5," Outer Radius of Outer Cylinder =
";OROS;LengthUnit$
PRINT #5," Yield Stress in Tension of Inner Cylinder =
";Mat$;PresUnit$
PRINT #5," Yield Stress in Tension of Outer Cylinder =
";OMat$;PresUnit$
PRINT #5," Poisson's Ratio of Inner Cylinder = ";poss$
PRINT #5," Poisson's Ratio of Outer Cylinder = ";Oposs$
PRINT #5," Pressure at Which Yielding Begins at the Bore
of Inner Cylinder= ";prnt51;PresUnit$
PRINT #5," Pressure at Which the Inner Cylinder is
Completely Yielded = ";prnt52;PresUnit$
PRINT #5," Autofrettage Pressure= ";prnt53;PresUnit$
PRINT #5," Depth of Yielding Caused by the
Autofrettage Pressure= ";dep$;LengthUnit$
PRINT #5," Operating Pressure= ";prnt54;PresUnit$
PRINT #5," Interface Pressure Between the Cylinders Caused by the
Shrinkfit= ";prnt55;PresUnit$
PRINT #5," Pressure at Which Yielding Will Reoccur at the Bore =
";prnt50;PresUnit$
PRINT #5," Factor of Safety = ";Factor$
PRINT #5," "
PRINT #5,bSchStr$
PRINT #5,bSchStr2$
PRINT #5,bSchStr3$
PRINT #5," "
CALL TEXTFACE(1)
PRINT #5,"Stresses in Inner Cylinder With the
Autofrettage Pressure Applied "
PRINT #5," "
CALL TEXTFACE(0)
PRINT #5," Radial stress at the bore =
";FIX(sigma(2,1));PresUnit$
PRINT #5," Hoop stress at the bore =
";FIX(sigma(3,1));PresUnit$
PRINT #5," Radial stress at the outer surface =
";FIX(sigma(2,innermeshplus));PresUnit$
PRINT #5," Hoop stress at the outer surface =
";FIX(sigma(3,innermeshplus));PresUnit$
PRINT #5," Maximum radial stress =
";FIX(sigma(2,maxlocationR));PresUnit$;" at
R=";(sigma(1,maxlocationR));LengthUnit$
PRINT #5," Maximum hoop stress =
";FIX(sigma(3,maxlocationT));PresUnit$;" at
R=";(sigma(1,maxlocationT));LengthUnit$
PRINT #5," "
CALL TEXTFACE(1)
PRINT #5,"Residual Stresses in Inner Cylinder After Autofrettage
Pressure is Released "
CALL TEXTFACE(0)
PRINT #5," "

```

```

        PRINT #5,"    Radial stress at the bore =
";FIX(Ressigma(2,1));PresUnit$
        PRINT #5,"    Hoop stress at the bore =
";FIX(Ressigma(3,1));PresUnit$
        PRINT #5,"    Radial stress at the outer surface =
";FIX(Ressigma(2,innermeshplus));PresUnit$
        PRINT #5,"    Hoop stress at the outer surface =
        PRINT #5,"    Maximum radial stress =
";FIX(Ressigma(2,maxlocationRares));PresUnit$;"    at
R=";(Ressigma(1,maxlocationRares));LengthUnit$
        PRINT #5,"    Maximum hoop stress =
";FIX(Ressigma(3,maxlocationTares));PresUnit$;"    at
R=";(Ressigma(1,maxlocationTares));LengthUnit$
        PRINT #5,"
        page 1 of 5"

```

CALL TEXTFACE(1)

```

        PRINT #5," "
        PRINT #5,"Total Residual Stress After the Shrinkfit "
        PRINT #5," "
        PRINT #5,"Stresses in Inner Cylinder "
        PRINT #5," "

```

CALL TEXTFACE(0)

```

        PRINT #5,"    Radial stress at the bore =
        PRINT #5,"    Hoop stress at the bore =
";FIX(Resshrksigma(3,1));PresUnit$
        PRINT #5,"    Radial stress at the outer surface =
";FIX(Resshrksigma(2,innermeshplus));PresUnit$
        PRINT #5,"    Hoop stress at the outer surface =
";FIX(Resshrksigma(3,innermeshplus));PresUnit$
        PRINT #5,"    Maximum radial stress =
";FIX(Resshrksigma(2,maxlocationRsres));PresUnit$;"    at
R=";(Resshrksigma(1,maxlocationRsres));LengthUnit$
        PRINT #5,"    Maximum hoop stress =
";FIX(Resshrksigma(3,maxlocationTsres));PresUnit$;"    at
R=";(Resshrksigma(1,maxlocationTsres));LengthUnit$
        PRINT #5," "

```

CALL TEXTFACE(1)

```

        PRINT #5,"Stresses in Outer Cylinder "

```

CALL TEXTFACE(0)

```

        PRINT #5," "
        PRINT #5,"    Radial stress at the bore =
";FIX(jshrksigma(2,1));PresUnit$
        PRINT #5,"    Hoop stress at the bore =
";FIX(jshrksigma(3,1));PresUnit$
        PRINT #5,"    Radial stress at the outer surface =
";FIX(jshrksigma(2,outermeshplus));PresUnit$
        PRINT #5,"    Hoop stress at the outer surface =
";FIX(jshrksigma(3,outermeshplus));PresUnit$

```

```

        PRINT #5,"    Maximum radial stress =
";FIX(jshrksigma(2,OmaxlocationRsres));PresUnit$;"    at
R=";(jshrksigma(1,OmaxlocationRsres));LengthUnit$
        PRINT #5,"    Maximum hoop stress =
";FIX(jshrksigma(3,OmaxlocationTsres));PresUnit$;"    at
R=";(jshrksigma(1,OmaxlocationTsres));LengthUnit$
        PRINT #5," "
        PRINT #5," "
        CALL TEXTFACE(1)
        PRINT #5,"Stresses Caused by Operating Pressure Only"
        PRINT #5," "
        PRINT #5," Stresses in the Inner Cylinder "
        CALL TEXTFACE(0)
        PRINT #5," "
        PRINT #5,"    Radial stress at the bore =
";FIX(designsigma(2,1));PresUnit$
        PRINT #5,"    Hoop stress at the bore =
";FIX(designsigma(3,1));PresUnit$
        PRINT #5,"    Radial stress at the outer surface =
";FIX(designsigma(2,innermeshplus));PresUnit$
        PRINT #5,"    Hoop stress at the outer surface =
";FIX(designsigma(3,innermeshplus));PresUnit$
        PRINT #5,"    Maximum radial stress =
";FIX(designsigma(2,ImaxRdoLoc));PresUnit$;"    at
R=";(designsigma(1,ImaxRdoLoc));LengthUnit$
        PRINT #5,"    Maximum hoop stress =
";FIX(designsigma(3,ImaxTdoLoc));PresUnit$;"    at
R=";(designsigma(1,ImaxTdoLoc));LengthUnit$
        PRINT #5," "
        CALL TEXTFACE(1)
        PRINT #5," Stresses in the Outer Cylinder "
        CALL TEXTFACE(0)
        PRINT #5," "
        PRINT #5,"    Radial stress at the bore =
";FIX(jdesignsigma(2,1));PresUnit$
        PRINT #5,"    Hoop stress at the bore =
";FIX(jdesignsigma(3,1));PresUnit$
        PRINT #5,"    Radial stress at the outer surface =
";FIX(jdesignsigma(2,outermeshplus));PresUnit$
        PRINT #5,"    Hoop stress at the outer surface =
";FIX(jdesignsigma(3,outermeshplus));PresUnit$
        PRINT #5,"    Maximum radial stress =
";FIX(jdesignsigma(2,OmaxRdoLoc));PresUnit$;"    at
R=";(jdesignsigma(1,OmaxRdoLoc));LengthUnit$
        PRINT #5,"    Maximum hoop stress =
";FIX(jdesignsigma(3,OmaxTdoLoc));PresUnit$;"    at
R=";(jdesignsigma(1,OmaxTdoLoc));LengthUnit$
        PRINT #5," "
        PRINT #5," "
        PRINT #5," "

```

PRINT #5,"
page 2 of 5"

```
CALL TEXTFACE(1)
PRINT #5,"Total Stress State With Operating Pressure      Applied "
PRINT #5," "
PRINT #5," Stresses in the Inner Cylinder "
CALL TEXTFACE(0)
PRINT #5," "
PRINT #5,"   Radial stress at the bore =
";FIX(Resdesignsigma(2,1));PresUnit$
PRINT #5,"   Hoop stress at the bore =
";FIX(Resdesignsigma(3,1));PresUnit$
PRINT #5,"   Radial stress at the outer surface =
";FIX(Resdesignsigma(2,innermeshplus));PresUnit$
PRINT #5,"   Hoop stress at the outer surface =
";FIX(Resdesignsigma(3,innermeshplus));PresUnit$
PRINT #5,"   Maximum radial stress =
";FIX(Resdesignsigma(2,ImaxRL));PresUnit$;"   at
R=";(Resdesignsigma(1,ImaxRL));LengthUnit$
PRINT #5,"   Maximum hoop stress =
";FIX(Resdesignsigma(3,ImaxTL));PresUnit$;"   at
R=";(Resdesignsigma(1,ImaxTL));LengthUnit$
PRINT #5," "
PRINT #5," "
CALL TEXTFACE(1)
PRINT #5," Stresses in the Outer Cylinder "
CALL TEXTFACE(0)
PRINT #5," "
PRINT #5,"   Radial stress at the bore =
";FIX(jResdesignsigma(2,1));PresUnit$
PRINT #5,"   Hoop stress at the bore =
";FIX(jResdesignsigma(3,1));PresUnit$
PRINT #5,"   Radial stress at the outer surface =
";FIX(jResdesignsigma(2,outermeshplus));PresUnit$
PRINT #5,"   Hoop stress at the outer surface =
";FIX(jResdesignsigma(3,outermeshplus));PresUnit$
PRINT #5,"   Maximum radial stress =
";FIX(jResdesignsigma(2,OmaxRL));PresUnit$;"   at
R=";(jResdesignsigma(1,OmaxRL));LengthUnit$
PRINT #5,"   Maximum hoop stress =
";FIX(jResdesignsigma(3,OmaxTL));PresUnit$;"   at
R=";(jResdesignsigma(1,OmaxTL));LengthUnit$
FOR i=1 TO 23
PRINT #5," "
NEXT i
PRINT #5,"
page 3 of 5"
PRINT #5," "
IF writefileflag=0 THEN
WINDOW 4,"printing window",(0,0)-(630,740),1
```

WINDOW OUTPUT 4
CALL TEXTFACE(1)
EDIT FIELD 222,"Now Printing Report, Please
Wait",(50,200)-(450,220),7,2
CALL TEXTFACE(0)

PICTURE ON
yoriginlocation=130
GOSUB SetGraphLocation
GOSUB graphwithpres
PICTURE OFF
graphic1\$=PICTURES
PICTURE ON:PICTURE OFF

yoriginlocation=360
GOSUB SetGraphLocation
PICTURE ON
GOSUB resautograph
PICTURE OFF
graphic2\$=PICTURES
PICTURE ON:PICTURE OFF

yoriginlocation=590
GOSUB SetGraphLocation
PICTURE ON
GOSUB shrinkprnt
EDIT FIELD 53,"page 4 of 5",(460,690)-(540,706),3,2
EDIT FIELD 247," ",(2000,2000)-(2020,2020),3,2
PICTURE OFF
graphic3\$=PICTURES
PICTURE ON:PICTURE OFF

PICTURE ON
yoriginlocation=130
GOSUB SetGraphLocation
GOSUB resshrinkprnt
PICTURE OFF
graphic4\$=PICTURES
PICTURE ON:PICTURE OFF

yoriginlocation=360
GOSUB SetGraphLocation
PICTURE ON
GOSUB designPrnt
PICTURE OFF
graphic5\$=PICTURES
PICTURE ON:PICTURE OFF

yoriginlocation=590
GOSUB SetGraphLocation
PICTURE ON

```

        GOSUB redesignPrnt
        EDIT FIELD 54,"page 5 of 5",(460,690)-(540,706),3,2
        EDIT FIELD 247," ",(2000,2000)-(2020,2020),3,2
    PICTURE OFF
        graphic6$=PICTURE$
    PICTURE ON:PICTURE OFF

    FOR i=1 TO 30
        PRINT #5," "
    NEXT i

    WINDOW OUTPUT #5
        PICTURE, graphic1$
        PICTURE, graphic2$
        PICTURE, graphic3$

    FOR i=1 TO 50
        PRINT #5," "
    NEXT i

        PICTURE, graphic4$
        PICTURE, graphic5$
        PICTURE, graphic6$
    END IF
    END IF
    CLOSE #5
    WINDOW CLOSE 4
        cleargraphflag=0
        graphtitleflag=0
        IF macsize$="small" THEN
            yoriginlocation=226      *** Set origin of graphs for on screen      viewing
        ELSE
            yoriginlocation=320
        END IF
        GOSUB SetGraphLocation

    RETURN

*****
** Clear factor of safety and reyielding pressure **
** when input data is changed **
*****
FactorSafeClear:
    Relyielding$=""
    Factor$=""
    EDIT FIELD 128,Relyielding$ ,(ef128x1,ef128y1)-(ef128x2,ef128y2),3,2
    EDIT FIELD 129,Factor$,(ef129x1,ef129y1)-(ef129x2,ef129y2),3,2
    RETURN

```

```

*****
** Find the maximum stresses with autop applied **
*****

findmaxwithautop:
Rmax=ABS(sigma(2,1))
Tmax=ABS(sigma(3,1))      ' find max stress
maxlocationR=1
maxlocationT=1
FOR i = 2 TO innermeshplus
    IF ABS(sigma(2,i))>Rmax THEN
        Rmax=ABS(sigma(2,i))
        maxlocationR=i
    END IF
    IF ABS(sigma(3,i))>Tmax THEN
        Tmax=ABS(sigma(3,i))
        maxlocationT=i
    END IF
NEXT i
RETURN

*****
** Find the maximum stresses in jacket for shrinkfit **
** For use during report **
*****

maxstressjshrk:
maxlocationRjsres=1
maxlocationTjsres=1
FOR i = 1 TO outermeshplus
    IF ABS(jshrksigma(2,i))>SRmax THEN
        SRmax=ABS(jshrksigma(2,i))
        maxlocationRjsres=i
    END IF
    IF ABS(jshrksigma(3,i))>STmax THEN
        STmax=ABS(jshrksigma(3,i))
        maxlocationTjsres=i
    END IF
NEXT i
RETURN

*****
** Find the locations of maximum stresses from **
** operating pressure only, For use during report **
*****

desmaxloc:
maxlocationAdesR=1
maxlocationAdesT=1
SRmax=ABS(designsigma(2,1))
STmax=ABS(designsigma(3,1))      ' find max stress
FOR i = 2 TO innermeshplus
    IF ABS(designsigma(2,i))>SRmax THEN
        SRmax=ABS(designsigma(2,i))

```

```

        maxlocationAdesR=i
    END IF
    IF ABS(designsigma(3,i))>STmax THEN
        STmax=ABS(designsigma(3,i))
        maxlocationAdesT=i
    END IF
NEXT i
RETURN

'*****
** Find the locations of maximum stresses from **
** operating pressure only, For use during report **
'*****
findshrinkmaxloc:
RETURN

'*****
** change drawing color **
'*****
ChangeColorGreen:
    forecolor 341
RETURN
ChangeColorBlack:
    forecolor 33
RETURN
ChangeColorRed:
    forecolor 205
RETURN

'*****
** set edit field locations for small mac screens **
'*****
smallmac:
'*** Main Window
win1x1=5
win1y1=40
win1x2=513
win1y2=340
'*** Reyielding
    ef128x1=295
    ef128y1=118
    ef128x2=380
    ef128y2=134
'****Factor of safety
    ef129x1=439
    ef129y1=118
    ef129x2=470
    ef129y2=134
'***** Bausinger Factor
    ef56x1=310
    ef56y1=1

```

```

ef56x2=480
ef56y2=16
***** Autofrettage pressure
ef4x1=125
ef4y1=105
ef4x2=220
ef4y2=119
***** Depth of yielding
ef5x1=125
ef5y1=121
ef5x2=220
ef5y2=135
***** Ipress
ef205x1=355
ef205y1=100
ef205x2=470
ef205y2=114
***** Bauschinger depth
ef57x1=200
ef57y1=1
ef57x2=310
ef57y2=16
**** Box in the screen
    box1x1=0
    box1y1=17
    box1x2=490
    box1y2=18
    box2x1=0
    box2y1=0
    box2x2=490
    box2y2=296
    box3x1=0
    box3y1=161
    box3x2=490
    box3y2=161
    box4x1=0
    box4y1=141
    box4x2=490
    box4y2=141
***** Problem Type Label
ef55x1=10
ef55y1=1
ef55x2=200
ef55y2=17
**** Inner radius inner cylinder label
ef111x1=2
ef111y1=19
ef111x2=90
ef111y2=34
**** Outer Radius Inner cylinder label
ef13x1=2

```

```

ef13y1=36
ef13x2=90
ef13y2=50
'*****Yield Stress (material property of inner cylinder) label
ef14x1=2
ef14y1=52
ef14x2=90
ef14y2=66
'*****yielding begins label
ef15x1=2
ef15y1=70
ef15x2=120
ef15y2=85
'*****yielding complete label
ef16x1=2
ef16y1=87
ef16x2=120
ef16y2=101
'*****Autofrettage precs label
ef17x1=2
ef17y1=103
ef17x2=120
ef17y2=118
'*****Depth of yielding label
ef18x1=2
ef18y1=120
ef18x2=120
ef18y2=135
'****Inner Radius Outer Cylinder label
ef120x1=225
ef120y1=20
ef120x2=350
ef120y2=34
'****Outer Radius Outer Cylinder label
ef121x1=225
ef121y1=36
ef121x2=350
ef121y2=50
'****Yield Stress label
ef122x1=225
ef122y1=52
ef122x2=350
ef122y2=66
'****Poisson's Ratio label
ef123x1=225
ef123y1=68
ef123x2=350
ef123y2=82
'****Design Pressure label
ef124x1=225
ef124y1=84

```

```

ef124x2=350
ef124y2=98
'****Interface Pressure label
ef125x1=225
ef125y1=100
ef125x2=350
ef125y2=114
'****ReYielding label
ef126x1=225
ef126y1=118
ef126x2=294
ef126y2=134
'****Safety label
ef127x1=390
ef127y1=118
ef127x2=435
ef127y2=134
'*****RIS
ef1x1=100
ef1y1=20
ef1x2=170
ef1y2=34
'*****ROS
ef2x1=100
ef2y1=36
ef2x2=170
ef2y2=50
'****Mat$
ef3x1=100
ef3y1=52
ef3x2=170
ef3y2=66
'****autoPS
ef4x1=125
ef4y1=105
ef4x2=220
ef4y2=119
'****Dep$
ef5x1=125
ef5y1=121
ef5x2=220
ef5y2=135
'****ORIS
ef6x1=355
ef6y1=20
ef6x2=470
ef6y2=34
'****OROS
ef7x1=355
ef7y1=36
ef7x2=470

```

```

ef7y2=50
'*****OMat$
ef8x1=355
ef8y1=52
ef8x2=470
ef8y2=66
'****poss$
ef9x1=355
ef9y1=68
ef9x2=470
ef9y2=82
'****DepPress$
ef11x1=355
ef11y1=84
ef11x2=470
ef11y2=98
'*****yieldbeg$
ef21x1=125
ef21y1=70
ef21x2=220
ef21y2=85
'*****yieldfin$
ef22x1=125
ef22y1=87
ef22x2=220
ef22y2=101
'*****Autofrettage  pres  label
ef27x1=355
ef27y1=100
ef27x2=470
ef27y2=114

```

RETURN

```

'*****
**  set edit field locations for big mac screens      **
'*****
bigmac:
'***  Main Window
win1x1=5
win1y1=40
win1x2=570
win1y2=440
'***  Reyielding
    ef128x1=335
    ef128y1=153
    ef128x2=450
    ef128y2=167
'****Factor of safety
    ef129x1=335
    ef129y1=169

```

```

ef129x2=450
ef129y2=183
***** Bausinger Factor
ef56x1=2
ef56y1=186
ef56x2=490
ef56y2=200
***** Autofrettage pressure
ef4x1=125
ef4y1=105
ef4x2=220
ef4y2=119
***** Depth of yielding
ef5x1=125
ef5y1=121
ef5x2=220
ef5y2=135
***** Ipress
ef205x1=335
ef205y1=137
ef205x2=450
ef205y2=151
***** Bauschinger depth
ef57x1=2
ef57y1=202
ef57x2=490
ef57y2=216
**** Box in the screen
box1x1=0
box1y1=17
box1x2=549
box1y2=17
box2x1=0
box2y1=0
box2x2=549
box2y2=399
box3x1=0
box3y1=235
box3x2=549
box3y2=235
box4x1=0
box4y1=255
box4x2=549
box4y2=255
box5x1=0
box5y1=102
box5x2=549
box5y2=102
***** Problem Type Label
ef55x1=70
ef55y1=1

```

```

ef55x2=400
ef55y2=17
'****Inner radius inner cylinder label
ef111x1=2
ef111y1=19
ef111x2=193
ef111y2=34
'****Outer Radius Inner cylinder label
ef13x1=2
ef13y1=36
ef13x2=193
ef13y2=50
'*****Yield Stress (material property of inner cylinder) label
ef14x1=2
ef14y1=52
ef14x2=193
ef14y2=66
'*****Autofrettage pres label
ef17x1=2
ef17y1=68
ef17x2=193
ef17y2=82
'*****Depth of yielding label
ef18x1=2
ef18y1=84
ef18x2=193
ef18y2=98
'*****yielding begins label
ef15x1=2
ef15y1=105
ef15x2=340
ef15y2=119
'*****yielding complete label
ef16x1=2
ef16y1=122
ef16x2=340
ef16y2=136
'****Inner Radius Outer Cylinder label
ef120x1=270
ef120y1=20
ef120x2=466
ef120y2=34
'****Outer Radius Outer Cylinder label
ef121x1=270
ef121y1=36
ef121x2=466
ef121y2=50
'****Yield Stress label
ef122x1=270
ef122y1=52
ef122x2=466

```

```

ef122y2=66
'****Poisson's Ratio label
ef123x1=268
ef123y1=68
ef123x2=378
ef123y2=82
'**** Inner Poissons label
ef148x1=375
ef148y1=68
ef148x2=410
ef148y2=82
'**** Outer Poissons label
ef149x1=463
ef149y1=68
ef149x2=503
ef149y2=82
'****Operating Pressure label
ef124x1=270
ef124y1=84
ef124x2=466
ef124y2=98
'****Interface Pressure label
ef125x1=2
ef125y1=138
ef125x2=340
ef125y2=152
'****ReYielding label
ef126x1=2
ef126y1=154
ef126x2=340
ef126y2=168
'****Safety label
ef127x1=2
ef127y1=170
ef127x2=340
ef127y2=184
'*****RIS
ef1x1=195
ef1y1=20
ef1x2=265
ef1y2=34
'*****RO$
ef2x1=195
ef2y1=36
ef2x2=265
ef2y2=50
'*****Mat$
ef3x1=195
ef3y1=52
ef3x2=265
ef3y2=66

```

```

'****autoPS
ef4x1=195
ef4y1=68
ef4x2=265
ef4y2=82
'****Dep$
ef5x1=195
ef5y1=84
ef5x2=265
ef5y2=98
'****ORIS
ef6x1=468
ef6y1=20
ef6x2=545
ef6y2=34
'****OROS
ef7x1=468
ef7y1=36
ef7x2=545
ef7y2=50
'*****OMat$
ef8x1=468
ef8y1=52
ef8x2=545
ef8y2=66
'****poss$
ef9x1=412
ef9y1=68
ef9x2=452
ef9y2=82
'****Oposs$
ef10x1=505
ef10y1=68
ef10x2=545
ef10y2=82
'****DepPress$
ef11x1=468
ef11y1=84
ef11x2=545
ef11y2=98
'*****yieldbeg$
ef21x1=335
ef21y1=105
ef21x2=450
ef21y2=119
'****yieldfin$
ef22x1=335
ef22y1=121
ef22x2=450
ef22y2=135
'*****Autofreitage pres label

```

```
ef27x1=355
ef27y1=100
ef27x2=470
ef27y2=114
```

RETURN

```
*****
** set up graph locations for report **
*****
SetGraphLocation:
**** edit field locations for coordinate systems
** "stress"
ef33x1=1
ef33y1=yoriginlocation-40
ef33x2=34
ef33y2=yoriginlocation-22
** "stress"
ef34x1=246
ef34y1=yoriginlocation-40
ef34x2=279
ef34y2=yoriginlocation-22
** "RI"
ef35x1=18
ef35y1=yoriginlocation-7
ef35x2=34
ef35y2=yoriginlocation+7
** "RI"
ef36x1=263
ef36y1=yoriginlocation-7
ef36x2=279
ef36y2=yoriginlocation+7
** "Ro"
ef37x1=226
ef37y1=yoriginlocation-7
ef37x2=242
ef37y2=yoriginlocation+7
** "Ro"
ef38x1=471
ef38y1=yoriginlocation-7
ef38x2=487
ef38y2=yoriginlocation+7
** "ORo"
ef137x1=226
ef137y1=yoriginlocation-7
ef137x2=248
ef137y2=yoriginlocation+7
** "ORo"
ef138x1=471
ef138y1=yoriginlocation-7
```

```

ef138x2=492
ef138y2=yoriginlocation+7
** "Radial Stress"
ef30x1=145
ef30y1=yoriginlocation+52
ef30x2=245
ef30y2=yoriginlocation+63
** "Hoop Stress"
ef31x1=350
ef31y1=yoriginlocation+52
ef31x2=450
ef31y2=yoriginlocation+63
** "Axes locations"
axes1x1=35
axes1y1=yoriginlocation-51
axes1x2=35
axes1y2=yoriginlocation+51
axes2x1=35
axes2y1=yoriginlocation
axes2x2=225
axes2y2=yoriginlocation
axes3x1=280
axes3y1=yoriginlocation-51
axes3x2=280
axes3y2=yoriginlocation+51
axes4x1=280
axes4y1=yoriginlocation
axes4x2=470
axes4y2=yoriginlocation

***** max and min stresses
** negative maximum radial stress
    ef32x1=1
    ef32y1=yoriginlocation+52
    ef32x2=70
    ef32y2=yoriginlocation+63
** negative maximum radial stress
    ef39x1=1
    ef39y1=yoriginlocation-63
    ef39x2=70
    ef39y2=yoriginlocation-52
** maximum hoop stress
    ef40x1=250
    ef40y1=yoriginlocation-63
    ef40x2=310
    ef40y2=yoriginlocation-52
** negative maximum hoop stress
    ef41x1=250
    ef41y1=yoriginlocation+52
    ef41x2=310
    ef41y2=yoriginlocation+63

```

```

***** graph titles
IF graphtitleflag=1 THEN
    Tit1=30
    Tit2=yoriginlocation-92
    Tit3=500
    Tit4=yoriginlocation-74
ELSE
    Tit1=30
    Tit2=yoriginlocation-82
    Tit3=500
    Tit4=yoriginlocation-64
END IF

**** graph stress lines
RySpan=51
RxSpan=190
    rStarty=yoriginlocation
    rStartx=35
    RoStartx=280
HySpan=51
HxSpan=190
    hStarty=yoriginlocation
    hStartx=280

RETURN

```

Vita

Richard Blaine Sparks was born in Bristol, Tennessee on August 26, 1962. He graduated from Bristol Tennessee High School in June, 1980. He entered East Tennessee State University in January, 1981 and transferred to the University of Tennessee, Knoxville in June, 1983. In December, 1987 he received the degree of Bachelor of Science in Engineering Science. In August, 1992 he received the degree of Master of Science in Engineering Science.

He is presently working on the degree of Doctor of Philosophy in Nuclear Engineering, at the University of Tennessee, Knoxville.