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CARTRIDGE CASE-CHAMBER INTERACTION DURING FIRING

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Frankford Arsenal
Philadelphia, Pennsylvania

December 1973

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A computer program has been written to determine the interference pressure between cartridge case and chamber and between cartridge case and bolt for the High Pressure, Thin-walled Cartridge Case Task in the Automatic Cannon Technology Program. Membrane stresses for conical and spherical sections are used along with the Prandtl-Reuss equations to determine the deformation of the case and the interference pressures during firing.

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ABSTRACT

A computer program has been written to determine the interference pressure between cartridge case and chamber and between cartridge case and bolt for the High Pressure, Thin-walled Cartridge Case Task in the Automatic Cannon Technology Program. Membrane stresses for conical and spherical sections are used along with the Prandtl-Reuss equations to determine the deformation of the case and the interference pressures during firing.

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GLOSSARY

α - Cone half-angle

σ_θ - Hoop stress

σ_r - Radial stress

σ_z - Axial stress

σ_y - Yield stress

σ_e - Effective stress

E - Young's Modulus for case

E^1 - Tangent modulus for strain hardening

E_{ch} - Young's Modulus for chamber

E_B - Young's Modulus for bolt

ν - Poisson's Ratio for case

ν_{ch} - Poisson's Ratio for chamber

ν_B - Poisson's Ratio for bolt

ϵ_t - Total strain

ϵ_p - Plastic component of strain

ϵ_θ - Plastic component of hoop strain

u - Displacement of case

u_{cl} - Clearance

u_{ch} - Displacement of chamber

u_B - Displacement of bolt

P_p - Propellant pressure

P_{pm} - Maximum propellant pressure

P_I - Interference pressure

r - Radius to midsurface of case

t - Case thickness

a - Inner radius of chamber or bolt face

b - Outer radius of barrel or bolt

r_m - Case midsurface radius at maximum pressure

a_m - Chamber or bolt inner radius at maximum pressure

b_m - Barrel or bolt outer radius at maximum pressure

INTRODUCTION

One of the most difficult parts of performing a stress analysis is the proper application of loads or boundary conditions. This is particularly true in the analysis of a cartridge case under firing conditions when the case is to function near the material capacity.

The preliminary structural analysis on the Automatic Cannon Technology (ACT) High Pressure, Thin-Walled Cartridge Case was conducted assuming the chamber to be rigid. At 75,000 psi the effective stress in the case reached approximately ninety (90) percent of the breaking strength of the material. The increase in deformation which would occur with a deformable chamber could be sufficient to allow the case to rupture. This necessitated the modeling of the interaction between the case and chamber.

A simplified model is developed which uses the membrane stresses[1] for a conical membrane and the Prandtl-Reuss[2] equations to determine the deformation of a section of the case. The equations[3] for the expansion of a thick walled cylinder under uniform pressure are used to represent the chamber. Continuity of stresses and displacements at the case - chamber interface allow the determination of the interference pressure as a function of propellant pressure. Since the base of the cartridge case is hemispherical, the procedure is repeated using the membrane stresses for a spherical membrane and the equations for the elastic deformation of a thick walled sphere under uniform internal pressure.

The case is assumed to be plastic when contact is made with the chamber. Both chamber and case expand until peak pressure is reached. At this point the case geometry is modified to reflect permanent deformation. Case and chamber then unload elastically until the propellant pressure goes to zero and a determination is made as to whether or not the case separates from the chamber.

---

[1] Wilhelm Flügge, "Stresses in Shells," Springer Verlag, Fourth Printing, New York, 1967.

[2] Alexander Mendelson, "Plasticity: Theory and Application," Macmillan, New York, 1968.

[3] Raymond J. Roark, "Formulas for Stress and Strain," McGraw-Hill, Third Edition, New York, 1954.

THEORY

Loading

The equations for the radial stress, hoop stress and longitudinal stress, respectively, for a conical membrane are

$$\sigma_r = -P$$

$$\sigma_\theta = \frac{Pr}{t\ \cos\alpha} \tag{1}$$

$$\sigma_z = \frac{Pr}{2t\ \cos\alpha}$$

The constitutive equation for a linear strain hardening material after yielding can be written as

$$\epsilon_t = \frac{\sigma_y}{E} + \frac{\sigma_e - \sigma_y}{E^1} \tag{2}$$

The plastic component of strain is given by

$$\epsilon_p = \epsilon_t - \frac{\sigma_e}{E} \tag{3}$$

and the radial displacement of the case is simply

$$u = r\epsilon_\theta \tag{4}$$

where

$$\epsilon_\theta = \frac{u}{r} = \frac{1}{E}\left\{\sigma_\theta - \nu\left[\sigma_r + \sigma_z\right]\right\} + \epsilon_\theta{}^P \tag{5}$$

The plastic component of the hoop strain is obtained from the Prandtl Reusse Equations and is given by

$$\epsilon_\theta{}^P = \frac{1}{2}\ \frac{\epsilon_p}{\sigma_e}\left\{2\sigma_\theta - \sigma_r - \sigma_z\right\} \tag{6}$$

The expression for the effective stress is

$$\sigma_e = \frac{1}{\sqrt{2}} \left\{ (\sigma_\theta - \sigma_r)^2 + (\sigma_r - \sigma_z)^2 + (\sigma_z - \sigma_\theta)^2 \right\}^{1/2} \qquad (7)$$

combining Equations 1, 2, 3, 4, 5, 6 and 7 yields

$$u = P \left\{ rg_3(r) \right\} \left\{ g_4(r) + E\,\bar{E}\,g_1 \frac{(r)}{2} \right\} - \bar{E} \frac{r\,\sigma_y\,g_1\,(r)}{2\,g_2(r)} \qquad (8)$$

where

$$\bar{E} = \frac{1}{E^1} - \frac{1}{E}$$

$$g_1(r) = 3 + \frac{2t\,\cos\alpha}{r}$$

$$g_2(r) = \left\{ 3 + \frac{6t\,\cos\alpha}{r} + \frac{4t^2\cos^2\alpha}{r^2} \right\}^{1/2} \qquad (9)$$

$$g_3(r) = \frac{r}{2t\,E\cos\alpha}$$

$$g_4(r) = 2 - \nu \left[1 - \frac{1}{Eg_3(r)} \right]$$

Equation 8 gives the total displacement of the case once yielding has occurred.

The pressure deforming the cartridge case is the difference between the interference pressure between case and chamber P_I, and the propellant pressure P_p. Hence, the deformation of the chamber can be written as

$$u_{ch} = u_c - u_{c1} \qquad (10)$$

Let

$$R_1 = rg_3(r) \left\{ g_4(r) + E\,\bar{E} \frac{g_1(r)}{2} \right\}$$

$$R_2 = - \frac{\bar{E}\,r\,\sigma_y\,g_1\,(r)}{2g_2(r)} \qquad (11)$$

Combining Equations 8, 9, 10 and 11 gives the interference pressure as a function of propellant pressure during loading and can be written as

$$P_I = \frac{P_p R_1 + R_2 - u_{c1}}{\left\{ \frac{a}{E_{ch}} \left(\frac{b^2 + a^2}{b^2 - a^2} + \nu_{ch} \right) + R_1 \right\}} \tag{12}$$

In a similar fashion, the relationships for a spherical membrane in contact with a thick elastic sphere combine to give the interference pressure between bolt and case for loading as

$$P_I = \frac{P_p R_3 + R_4 - u_{c1}}{\left\{ \frac{a}{2\, E_B \, (b^3 - a^3)} \left[2a^3 \, (1 - 2\nu_B) + b^3 \, (1 + \nu_B) \right] + R_3 \right\}} \tag{13}$$

where

$$R_3 = \frac{r}{E} \left[(1 - \nu) \, \frac{a}{2t} + \nu \right] + \frac{r\bar{E}}{2} \left[\frac{r}{2t} + 1 \right]$$

$$R_4 = - \frac{r \, \sigma_y \, \bar{E}}{2}$$

Unloading

During unloading the behavior of both case and chamber or case and bolt is considered to be strictly elastic. The dimensions used are the dimensions calculated at peak pressure. A negative pressure is applied to the case and compatibility of radial stress and displacement is maintained at the interface between the case and chamber or case and bolt.

The results of this procedure are then superposed on the loading equations at peak pressure and the interference pressure is determined as a function of propellant pressure during unloading.

The equations used for unloading are the same as loading without the plastic component of strain.

For the case - chamber interaction the interference pressure to be superposed on the maximum interference pressure is

$$P_I^{1} = \frac{(P_{pm} - P_p)\, h_1(r)}{h_1(r) + h_2(r)} \tag{14}$$

where

$$h_1(r) = \frac{r_m^{2}}{2\, Et \cos\alpha} \left\{ 2 - \nu \left[1 - \frac{2t \cos\alpha}{r_m} \right] \right\}$$

$$h_2(r) = \frac{a_m}{E_{ch}} \left\{ \frac{b_m^{2} + a_m^{2}}{b_m^{2} - a_m^{2}} + \nu_{ch} \right\}$$

and the interference pressure during unloading is given by

$$P_I = \frac{(P_p - P_{pm})\, h_1(r)}{h_1(r) + h_2(r)} + \frac{R_1 P_{pm} + R_2 - u_{c1}}{\left\{ \frac{a_m}{E_{ch}} \left(\frac{b_m^{2} + a_m^{2}}{b_m^{2} - a_m^{2}} + \nu_{ch} \right) + R_1 \right\}} \tag{15}$$

for the case bolt interaction the corresponding terms are

$$P_I^{1} = \frac{(P_{pm} - P_p)\, h_3(r)}{h_3(r) + h_4(r)} \tag{16}$$

where

$$h_3(r) = \frac{r_m^{2}}{E} \left\{ (1 - \nu) \frac{r_m}{2t} + \nu \right\}$$

$$h_4(r) = \frac{a_m}{2\, E_B\, (b_m^{3} - a_m^{3})} \left\{ 2\, a_m^{3}\, (1 - 2\, \nu_B) + b^{3}\, (1 + \nu_B) \right.$$

and

$$P_I = \frac{(P_p - P_{pm})\, h_3(r)}{h_3(r) + h_4(r)} + \frac{R_3 P_{pm} + R_4 - u_{c1}}{\left\{ \frac{a_m}{2\, E_B\, (b_m^{3} - a_m^{3})} \left[2a_m^{3}\, (1 - 2\nu_B) + b_m^{3}\, (1 + \nu_B) \right] + R_3 \right\}} \tag{17}$$

To determine when separation of case and chamber or case and bolt occurs P_I is set equal to zero and the equation is solved for P_p.

For the case - chamber interaction this is

$$P_p = \left\{ \frac{h_1(r) + h_2(r)}{h_1(r)} \right\} \left\{ \frac{P_{pm}\, h_1(r)}{h_1(r) + h_2(r)} - \frac{R_1\, P_{pm} + R_2 - u_{cl}}{\frac{a_m}{E_{ch}} \left(\frac{b_m^2 + a_m^2}{b_m^2 - a_m^2} + \nu_{ch} \right) + R_1} \right\} \tag{18}$$

and for the case - bolt interaction this is

$$P_p = \left\{ \frac{h_3(r) + h_4(r)}{h_3(r)} \right\} \left\{ \frac{P_{pm}\, h_3(r)}{h_3(r) + h_4(r)} - \frac{R_3\, P_{pm} + R_4 - u_{cl}}{\frac{a_m}{2\, E_B\, (b_m^3 - a_m^3)} \left(2a_m^3 \left[1 - 2\nu_B\right] + b_m^3 \left[1 + \nu_B\right] \right) + R_3} \right\} \tag{19}$$

If the values obtained from either Equation 18 or 19 are negative, then the case does not separate from the bolt or chamber and extraction forces could be higher than desirable.

COMPUTER PROGRAM

The program is written in the "Algebraic" language and can be run on an expanded core desk top computer. The language is sufficiently conversational and should present no difficulties in translating to Fortran IV. A flow chart and a program listing can be found in the appendix.

The cartridge case material is represented by a bilinear stress - strain curve while the chamber and bolt are assumed to remain elastic. It is further assumed that the case goes plastic before it reaches the chamber. Material parameters for the case, chamber, and bolt are input variables in the program. All geometries as well as maximum pressure and the number of steps to reach that pressure are input variables. A control number is entered to determine if the analysis will proceed as a conical membrane within a thick walled cylinder (chamber) or a spherical membrane within a thick walled sphere (bolt).

The computation proceeds without output until clearance is exceeded. At this point, the program interprets linearly between the step previous to contact and the step after contact to determine propellant pressure at the instant of contact between the case and chamber. The case and chamber then expand together until peak pressure is reached. At each pressure step, propellant pressure, interference pressure and displacement are printed. When peak pressure is reached, "LOADING COMPLETE" is printed. Unloading then proceeds until the interference pressure goes to zero or the propellant pressure goes to zero. If the interference pressure goes to zero, the program prints "SEPARATION AT PRESS =" and gives the corresponding propellant pressure.

The program then prints the displacement at zero propellant pressure and that the unloading is complete. If the interference pressure does not go to zero, then the program prints the interference pressure and displacement at zero propellant pressure. A program stop is executed which allows the operator to print comments on the output. A control number is then entered and the program can be recycled without the necessity of again entering some of the parameters; however, it is possible to again enter all of the parameters.

RESULTS AND CONCLUSIONS

The case - chamber - bolt configuration for this analysis is shown in Figure 1. The case is the High Pressure, Thin-Walled concept under development for the Automatic Cannon Technology program. The chamber and breech are a modified version of a standard 30 mm Mann barrel and breech. Data used for the case was obtained from stress - strain data for 1030 steel and is approximated by a bilinear stress - strain curve.

A modulus of 30×10^6 psi and a poisson's ratio of 0.3 are used for both chamber and bolt. The pressure was taken to a maximum of 75,000 psi and then unloaded to zero propellant pressure. The interference pressure between case and chamber and between case and bolt are shown in Figure 2a as a function of location along the case after the propellant pressure has unloaded to zero. Figure 2b shows a cross section of the case to indicate the corresponding interference pressure shown in Figure 2a. Notice that the interference pressures are generally lower in the spherical region of the case. Separation from the bolt face is also indicated for a small section of the spherical end. The interference pressures throughout the rest of the case are high, primarily as a result of the case and chamber unloading along the same modulus and the geometry. In the regions where the barrel thickness increases, the interference pressure drops slightly.

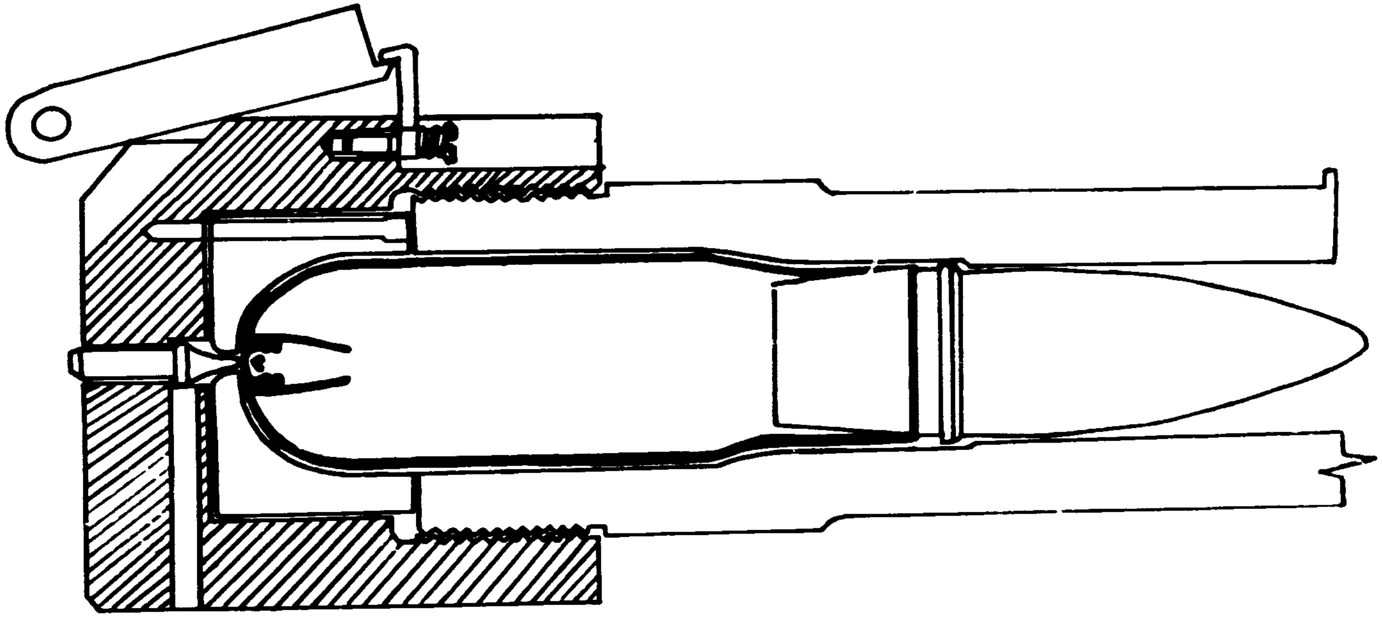


Figure 1. Case - Chamber - Bolt Configuration

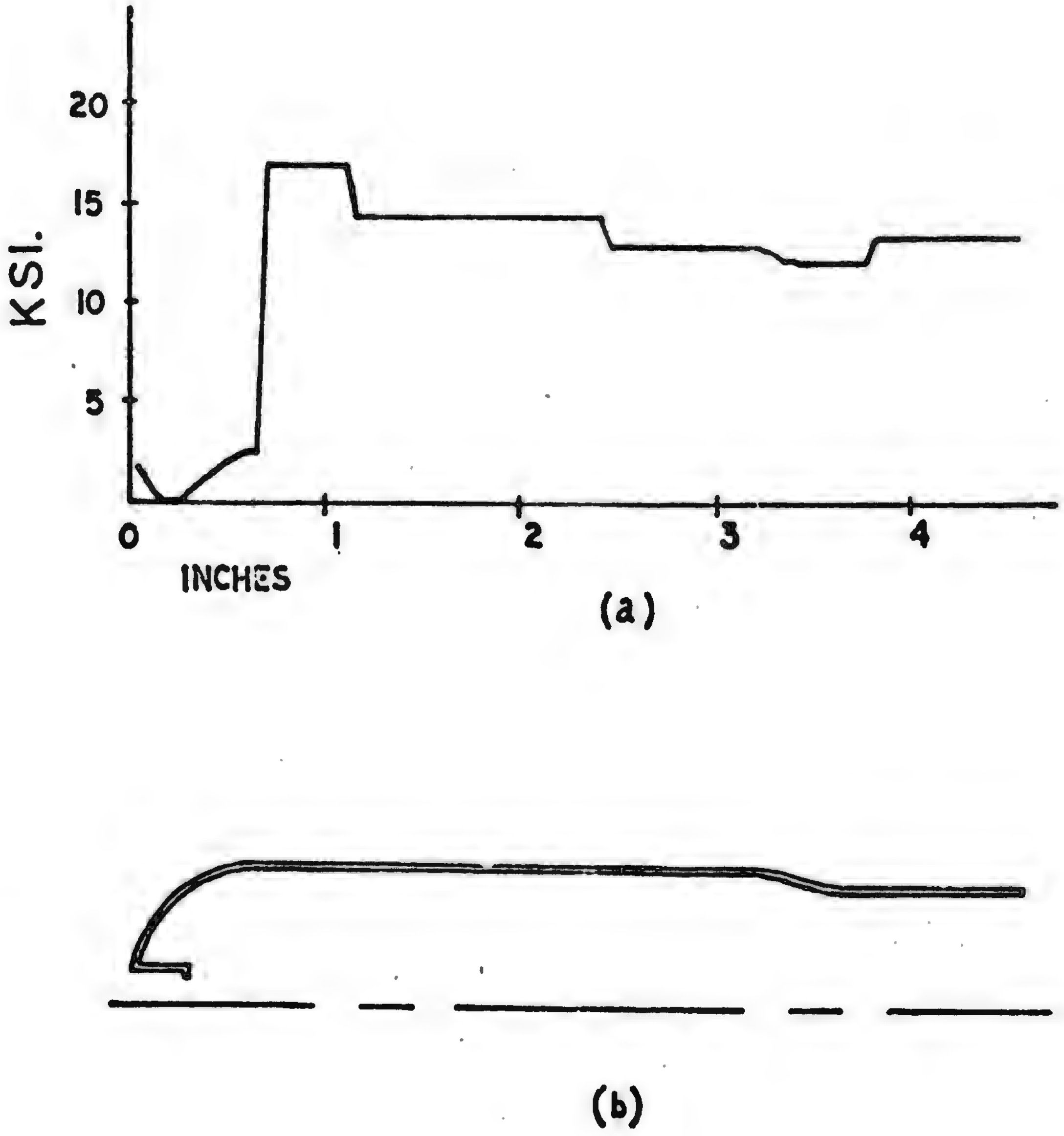


Figure 2. (a) Interference Pressure Between Case, Chamber and Bolt After Unloading

(b) Case Cross-section Corresponding to Interference Pressure Locations

The results of this analysis indicate that extraction would be extremely difficult because of the large deformation at peak pressure and because both case and chamber are steel. Some other runs of the program indicate that raising the ratio of chamber to case moduli tends to lower the interference pressures.

While quantitative verification is not planned, there has been qualitative verification of the results from other programs. Steel cases of standard type have been fired in a Mann barrel at high pressures on other programs and high interference pressures were indicated by the need to forcibly extract the case.

The results of this type of analysis provides the boundary conditions necessary to perform a stress analysis by finite element techniques or other procedures by establishing both a pressure and displacement history during firing for the outer surface of the cartridge case.

REFERENCES

1. Wilhem Flügge, "Stresses in Shells," Springer Verlag, Fourth Printing, New York, 1967.
2. Alexander Mendelson, "Plasticity: Theory and Application," Macmillan, New York, 1968.
3. Raymond J. Roark, "Formulas for Stress and Strain," McGraw-Hill, Third Edition, New York, 1954.

APPENDIX A

Program Nomenclature

A - Barrel radius, inside (A)

B - Barrel radius, outside (B)

C - Case thickness (T)

X - Radius of case midsurface (R)

Y - Clearance (UCL)

Z - Case elastic modulus (EC)

R1 - Poisson's ratio for case (V)

R2 - Strain hardening tangent modulus for case (EPRIM)

R3 - Case yield stress (SIGY)

R4 - Chamber modulus of bolt modulus (ECH or EB)

R5 - Chamber or bolt Poisson's ratio (VCH or VB)

R6 - Slope of case (half angle - ALPHA)

R7 - Maximum pressure

R8 - Storage register (X)

R9 - Control number (cylinder or bolt)

R10 - Intermediate calculation

R11 - Intermediate calculation

R12 - Intermediate calculation

R13 - Pressure increment

R14 - Pressure increment multiplier

R15 - Pressure

R16 - Interference pressure

R17 - Storage register

R18 - Propellant pressure at contact

R19 - Maximum displacement of case

R20 - Maximum displacement of chamber

R21 - Maximum displacement of outside barrel radius

R22 - Maximum interference pressure

R23 - $h_1(r)$ or $h_3(r)$

R24 - $h_2(r)$ or $h_4(r)$

R25 - Number of increments in pressure

R26 - $g_1(r)$

R27 - $g_2(r)$

R28 - $g_3(r)$

R29 - $g_4(r)$

R30 - Storage register for A

R31 - Storage register for B

R32 - Recycle command

R33 - Displacement of case

R34 - Maximum displacement of case

APPENDIX B

Program

```
0:
CFG 1;0→R1→R2→R3
→R4→R5→R6→R7→R8→
R9→R10→R11→R12→R
13→R14→R15⊢
1:
0→R16→R17→R18→R1
9→R20→R21→R22→R2
3→R24→R25→R26→R2
7→R28→R29⊢
2:
0→R30→R31→R32⊢
3:
"0";ENT "CYL/SPH
 1 OR 0",R9⊢
4:
ENT "T=?",C,"R=?
",X,"A=?",A,"B=?
",B,"UCL=?",Y,"E
C=?",Z,"ECH,EB=?
",R4⊢
5:
ENT "EPRIM=?",R2
,"V=?",R1,"VCH,V
B=?",R5,"SIGY=?"
,R3⊢
6:
X→R8;A→R30;B→R31
;IF R9=1;ENT "AL
PHA=?",R6⊢
7:
ENT "MAX PRESS=?
",R7,"NO. INCREM
ENTS=?",R25⊢
8:
IF R9=0;GTO "1"⊢
9:
PRT "***********
*****";SPC ⊢
10:
PRT "  CASE-CHAM
BER","  INTERACT
ION";SPC 1;PRT "
****************
";SPC ⊢
11:
3+2CCOS R6/X→R26
⊢
12:
√(3+6CCOS R6/X+4
CCOS R6↑2/X↑2)→
R27⊢
13:
X/2C2COS R6→R28⊢
14:
2-R1(1-1/2R28)→R
29⊢
15:
XR28(R29+Z(1/R2-
1/Z)R26/2)→R10⊢
16:
-(1/R2-1/Z)XR3R2
6/2R27→R11⊢
17:
(A/R4)((B↑2+A↑2)
/(B↑2-A↑2)+R5)+R
10→R12⊢
18:
GTO "2"⊢
19:
"1";PRT "*******
*********";SPC ⊢
20:
PRT "   CASE-BOL
T","  INTERACTIO
N";SPC ;PRT "***
*************";
SPC ⊢
21:
(X/Z)((1-R1)X/2C
+R1)+(X(1/R2-1/Z
)/2)(X/2C+1)→R10
⊢
22:
-(XR3/2)(1/R2-1/
Z)→R11⊢
23:
(A/2R4(B↑3-A↑3))
(2A↑3(1-2R5)+B↑3
(1+R5))+R10→R12⊢
24:
"2";SPC 2;FXD 4;
PRT "RADIUS=",X,
"THICK=",C,"A=",
A,"B=",B,"UCL=",
Y⊢
25:
PRT "VC=",R1,"VC
H OR VB=",R5;
FXD 2;PRT "EC=",
Z,"ECH OR EB=",R
4⊢
26:
PRT "EPRIM=",R2,
"SIGY=",R3,"MAX
PRESS=",R7⊢
27:
IF R9=1;PRT "ALP
HA=",R6⊢
28:
SPC ;PRT "******
**********";SPC
⊢
29:
R7/R25→R13;0→R14
⊢
30:
"3";1+R14→R14;R1
3*R14→R15⊢
31:
(R15*R10+R11-Y)/
R12→R16;IF R16>0
;IF R14=1;(Y-R11
)/R10→R18;GTO "4
4"⊢
32:
IF R16≤0;R16→R17
;SFG 1;GTO "3"⊢
33:
IF FLG 1;CFG 1;
GTO "4"⊢
34:
GTO "5"⊢
35:
"4";(Y-R11)/R10→
R18⊢
36:
"44";PRT "CONTAC
T AT P=",R18;
SPC ⊢
37:
PRT "***********
*****";SPC ⊢
38:
"5";(R15-R16)R10
+R11→R33;FXD 2⊢
39:
PRT "PROP PRESS=
",R15,"INTF PRES
S=",R16;FXD 6;
PRT "     U=",R3
3;SPC 2⊢
40:
IF R7>R15;GTO "3
```

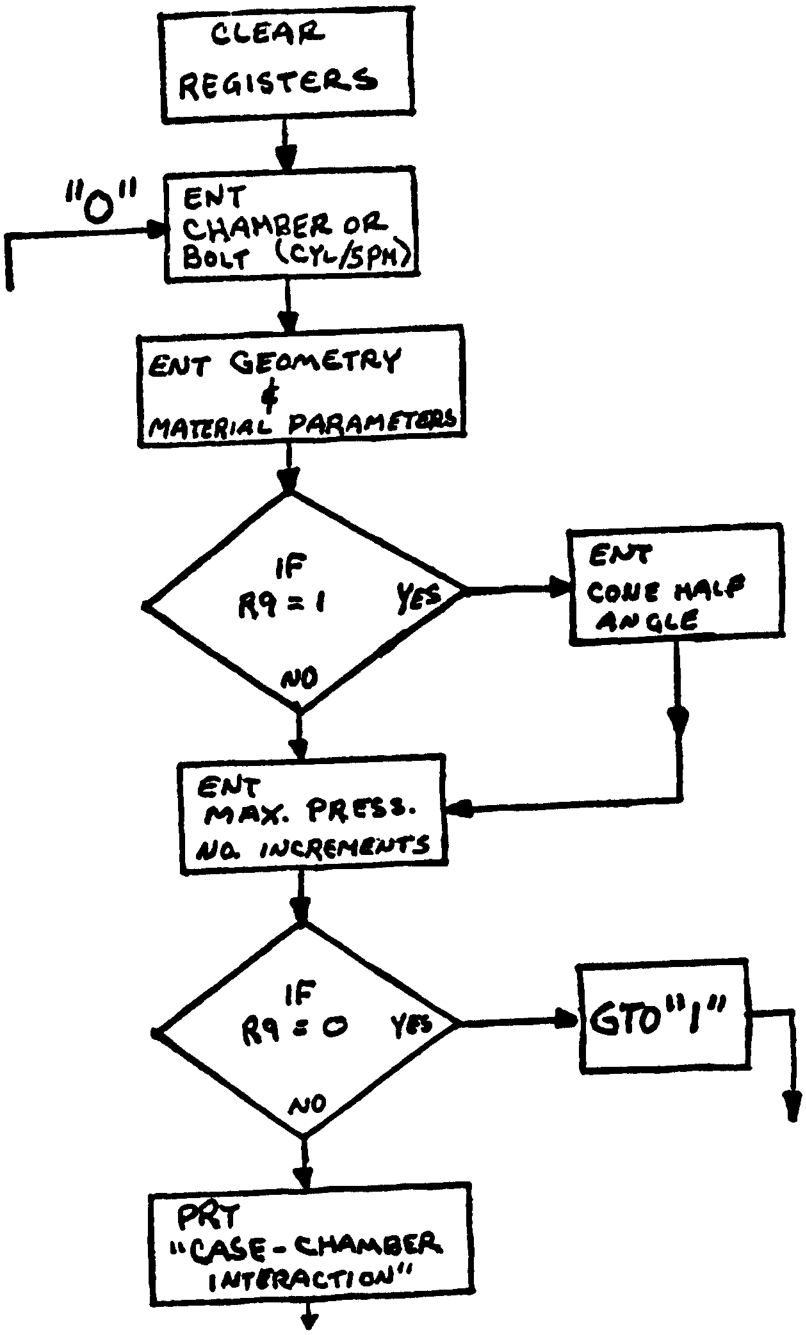
```
41:
PRT "************
*****";SPC ⊦
42:
PRT       LOADING
","    COMPLETE"
;SPC ;PRT "*****
************";
SPC 2⊦
43:
(R15-R16)R10+R11
→R19⊦
44:
R19-Y→R20⊦
45:
X+R19→X;A+R20→A⊦
46:
IF R9=0;GTO "6"⊦
47:
(R16*B/R4)(2A↑2/
(B↑2-A↑2))→R21⊦
48:
GTO "7"⊦
49:
"6":(3R16/2R4)((
1-R5)/(B↑3-A↑3))
BA↑3→R21⊦
50:
"7":B+R21→B;R16→
R22;0→R14;R33→R3
4⊦
51:
IF R9=0;GTO "8"⊦
52:
XX/2ZCCOS R6(2-R
1(1-2CCOS R6/X))
→R23⊦
53:
(A/R4)((B↑2+A↑2)
/(B↑2-A↑2)+R5)→R
24⊦
54:
GTO "9"⊦
55:
"8":(XX/Z)((1-R1
)X/2C-R1)→R23⊦
56:
(A/2R4(B↑3-A↑3))
(2A↑3(1-2R5)+B↑3
(1+R5))→R24⊦
57:
"9":1+R14→R14⊦
```

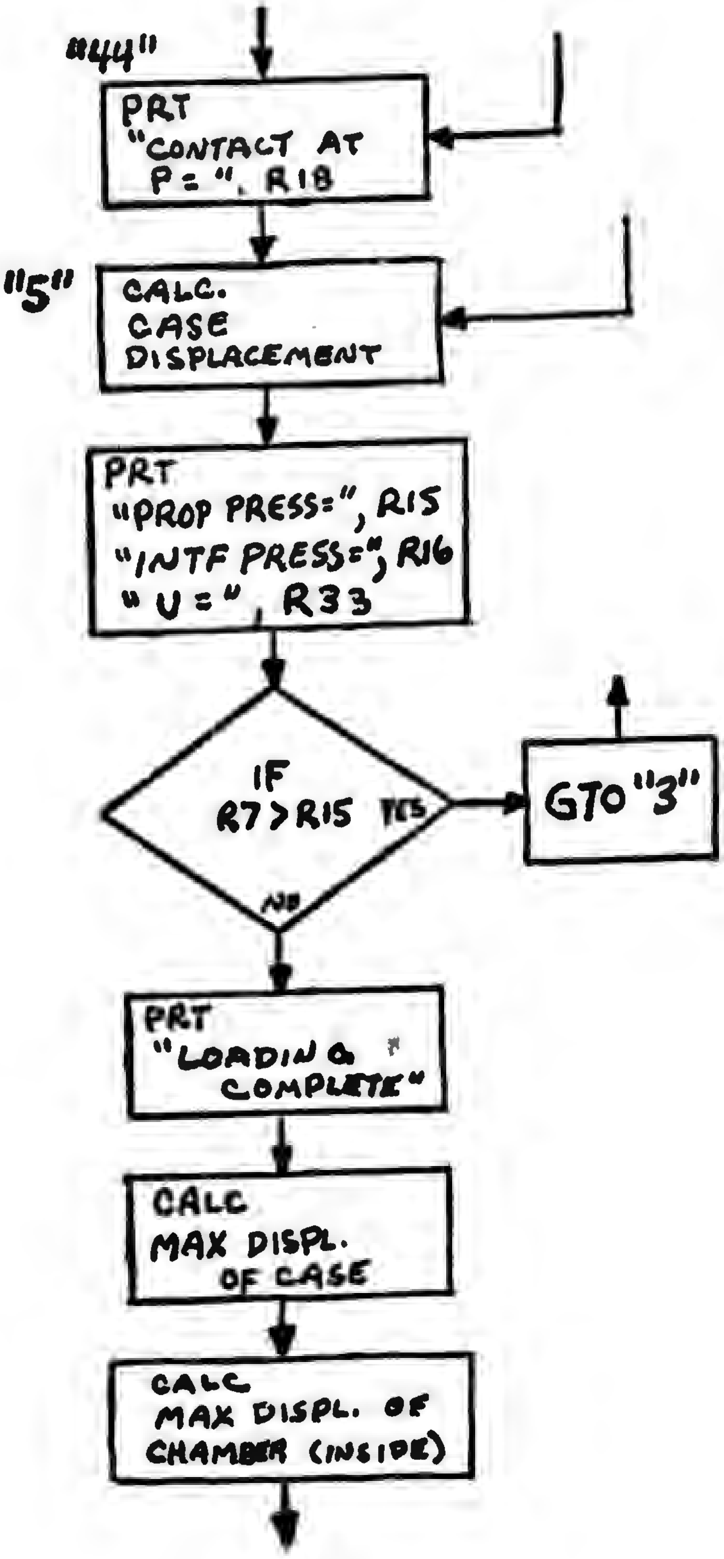
```
58:
R7-R13*R14→R15⊦
59:
R23(R15-R7)/(R23
+R24)+R22→R16⊦
60:
IF R16>0;GTO "10
"⊦
61:
R7-R22(R23+R24)/
R23→R15⊦
62:
PRT "************
*****";SPC ⊦
63:
Y-R15R23→R33⊦
64:
FXD 2;PRT "    SE
PARATION","    AT
 PRESS=",R15;
SPC ;PRT "******
***********"⊦
65:
FXD 6;SPC ;PRT "
AT PRESS = 0.00"
;FXD 6;SPC ;PRT
"       U=",R33;
SPC ⊦
66:
SPC ;PRT "******
***********";SPC
;FXD 2⊦
67:
PRT "    UNLOADIN
G","    COMPLETE
";SPC ;PRT "****
*************";
SPC 3⊦
68:
GTO "11"⊦
69:
"10":-(R22-R16)R
24→R33;R33+R34→R
33;FXD 2⊦
70:
PRT "PROF PRESS=
",R15,"INTF PRES
S=",R13;FXD 6;
PRT "       U=",R3
3;SPC 2⊦
```

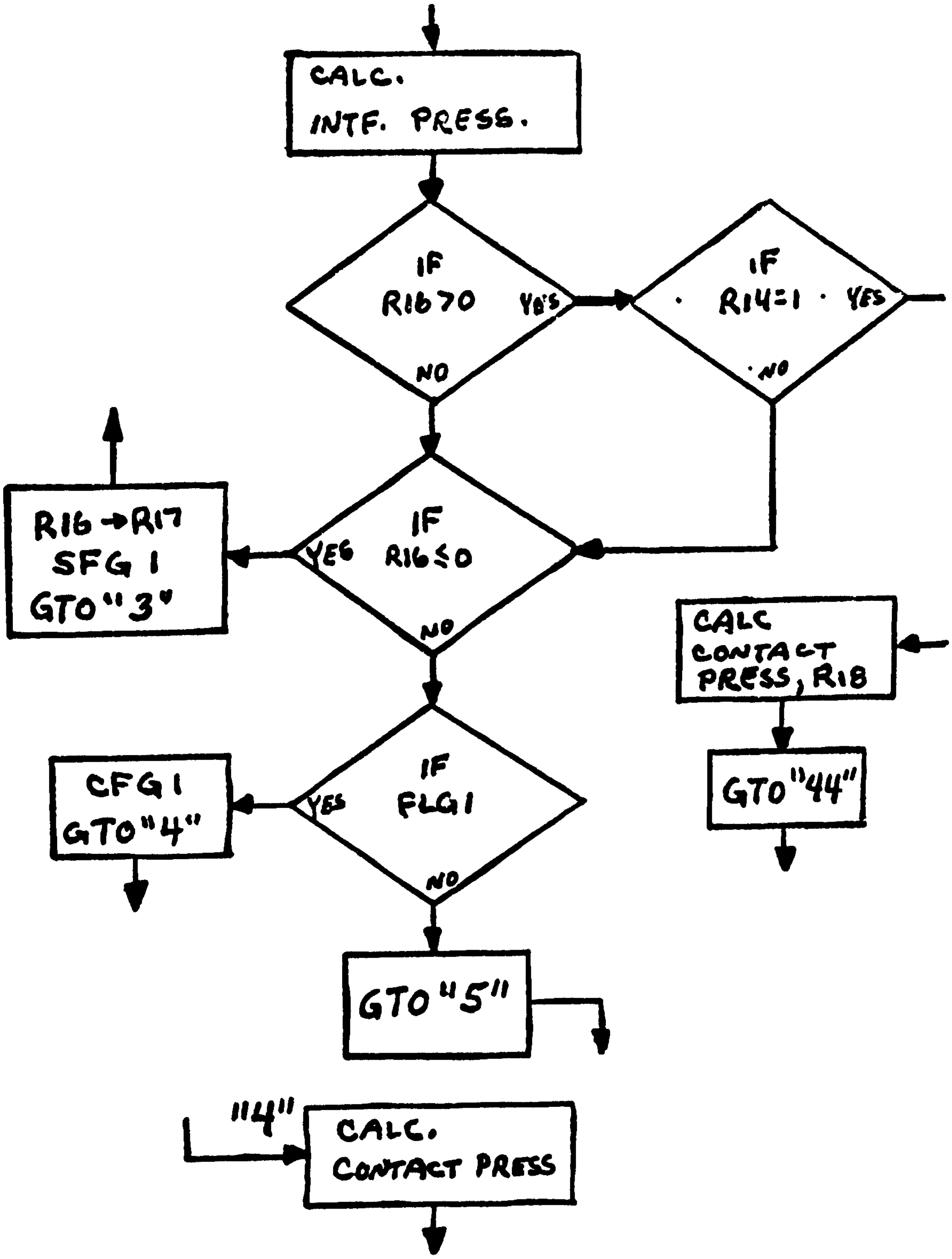
```
71:
GTO "9";IF R15=0
;PRT "**********
******","*******
*********";SPC 3
;GTO "11"⊦
72:
"11";DSP "COMMEN
TS ?";STP ⊦
73:
ENT "RECYCLE? 1
OR 0",R32⊦
74:
IF R32=1;R8→X;R3
0→A;R31→B;SPC 5;
GTO "0"⊦
75:
END ⊦
R68
```

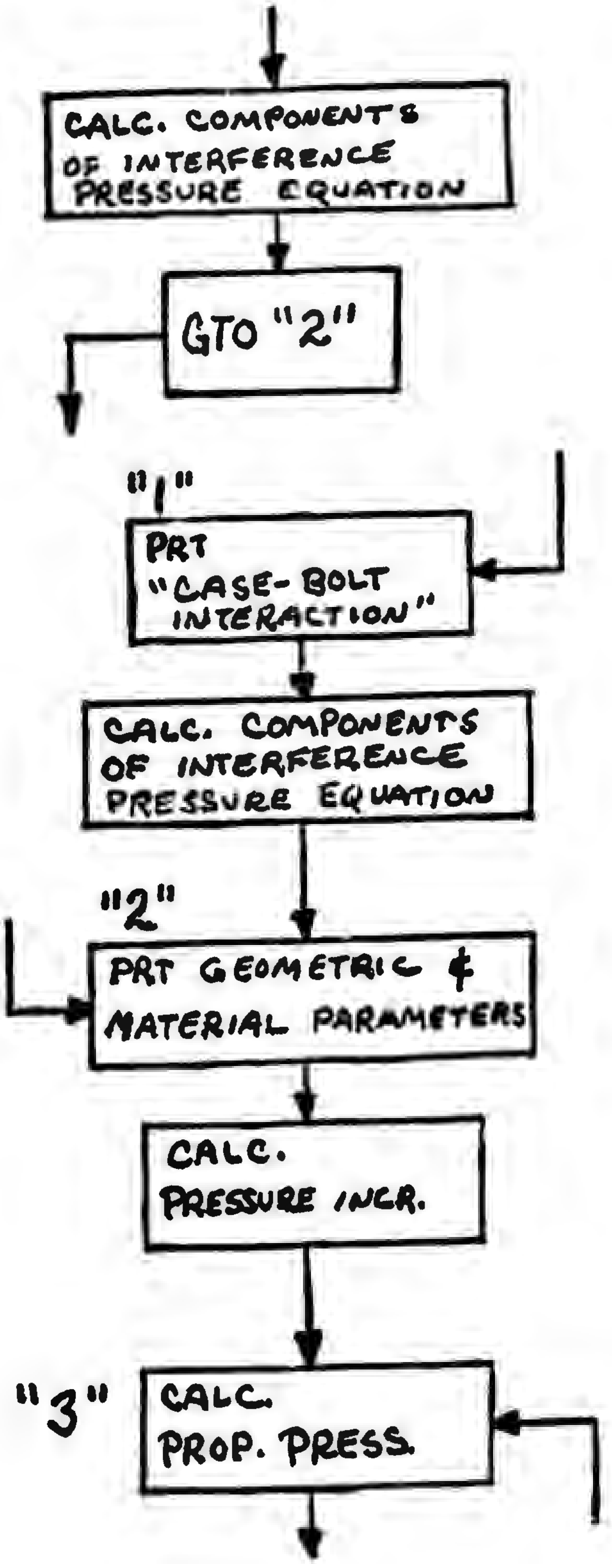
APPENDIX C

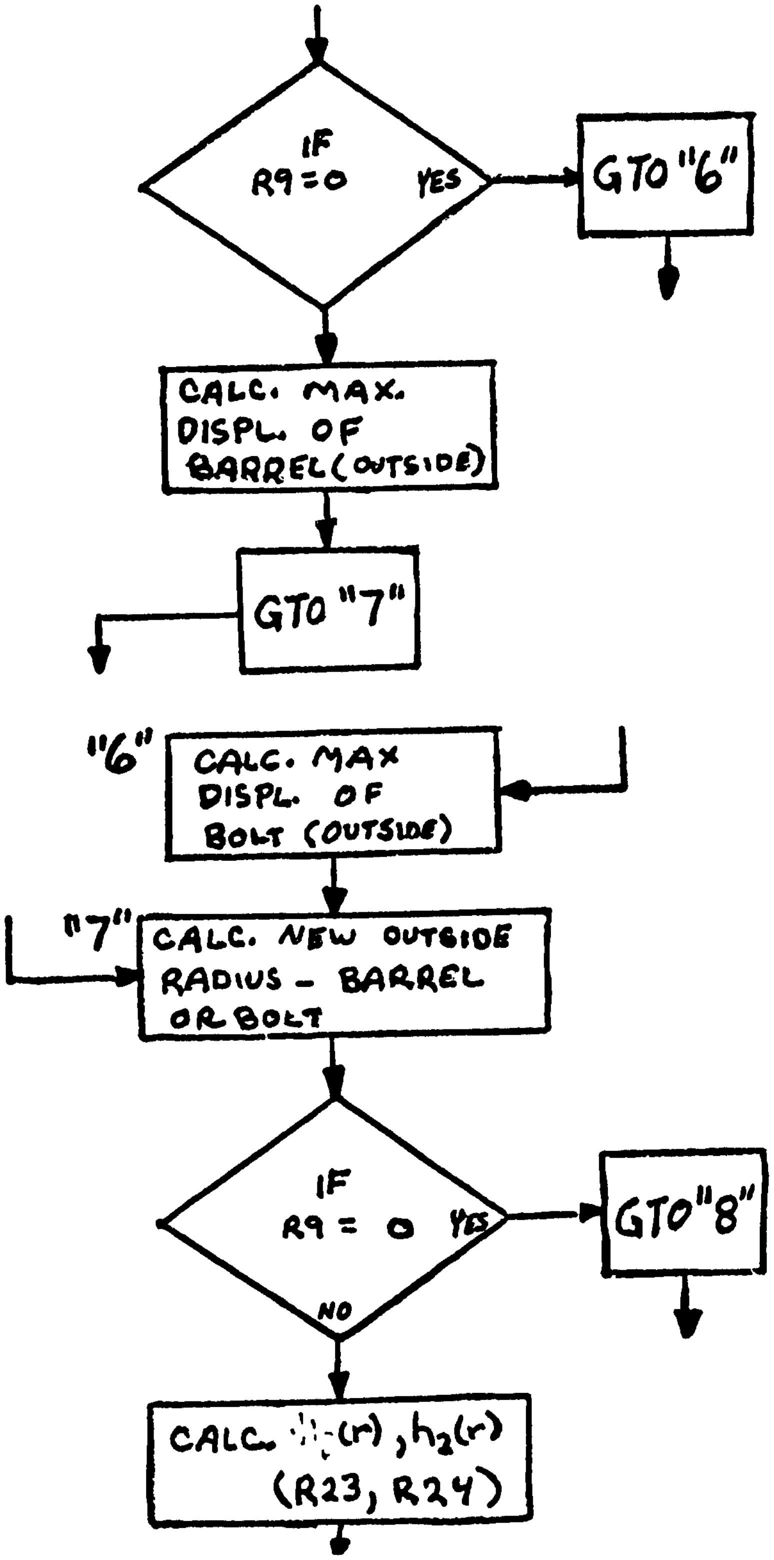
Flow Chart

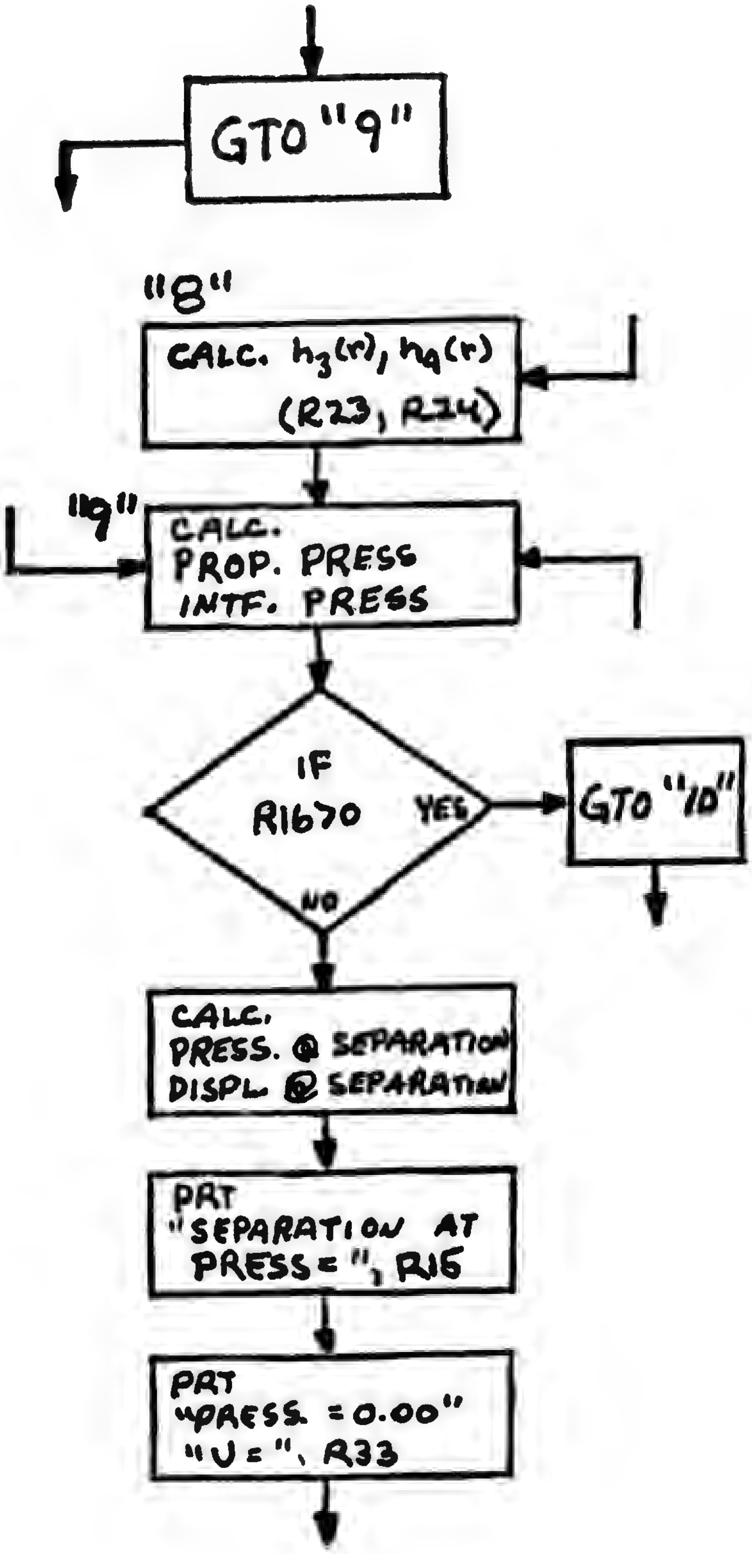


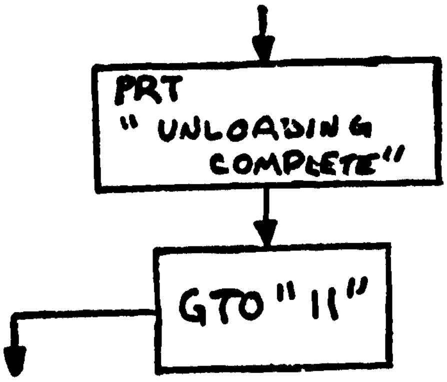

"44"
PRT "CONTACT AT P=", R18
"5"
CALC. CASE DISPLACEMENT
PRT "PROP PRESS=", R15 "INTF PRESS=", R16 "U=", R33
IF R7>R15
YES
NO
GTO "3"
PRT "LOADING COMPLETE"
CALC MAX DISPL. OF CASE
CALC MAX DISPL. OF CHAMBER (INSIDE)

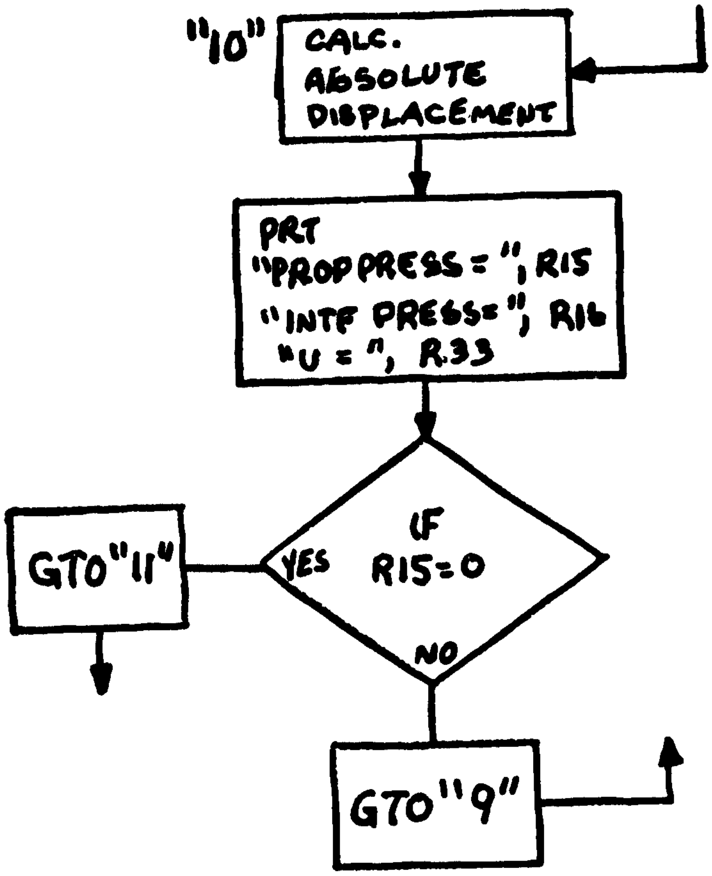

CALC.
INTF. PRESS.
IF
R16>0
YES
NO
IF
R14=1
YES
NO
R16→R17
SFG1
GTO"3"
IF
R16≤0
YES
NO
CALC
CONTACT
PRESS, R18
GTO"44"
CFG1
GTO"4"
IF
FLG1
YES
NO
GTO"5"
"4"
CALC.
CONTACT PRESS

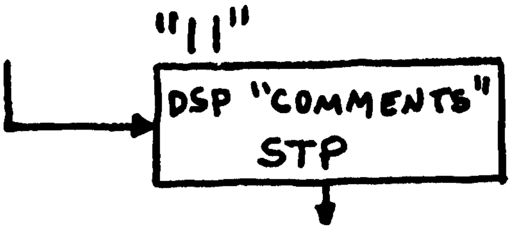

CALC. COMPONENTS OF INTERFERENCE PRESSURE EQUATION
GTO "2"
"1"
PRT "CASE-BOLT INTERACTION"
CALC. COMPONENTS OF INTERFERENCE PRESSURE EQUATION
"2"
PRT GEOMETRIC & MATERIAL PARAMETERS
CALC. PRESSURE INCR.
"3"
CALC. PROP. PRESS.

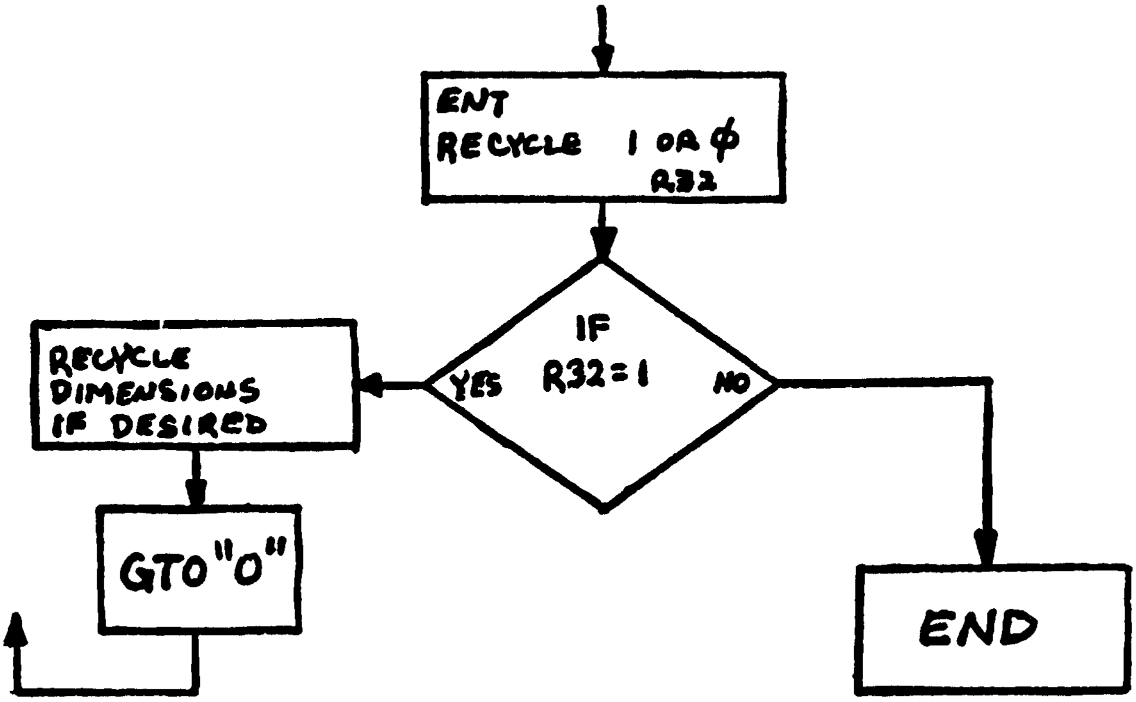

IF R9=0
YES
GTO "6"
CALC. MAX. DISPL. OF BARREL (OUTSIDE)
GTO "7"
"6"
CALC. MAX DISPL. OF BOLT (OUTSIDE)
"7"
CALC. NEW OUTSIDE RADIUS - BARREL OR BOLT
IF R9 = 0
YES
NO
GTO "8"
CALC. h1(r), h2(r) (R23, R24)


GTO "9"
"8"
CALC. h3(r), h4(r) (R23, R24)
"9"
CALC.
PROP. PRESS
INTF. PRESS
IF R16>0
YES
NO
GTO "10"
CALC.
PRESS. @ SEPARATION
DISPL. @ SEPARATION
PRT "SEPARATION AT PRESS=", R15
PRT "PRESS. =0.00"
"U=", R33


PRT
" UNLOADING COMPLETE"
GTO "11"


"10"
CALC. ABSOLUTE DISPLACEMENT
PRT
"PROP PRESS = "; R15
"INTF PRESS= "; R16
"U = ", R33
IF R15=0
YES
NO
GTO"11"
GTO"9"


"11"
DSP "COMMENTS"
STP


ENT
RECYCLE 1 OR 0
R32
IF
R32=1
YES
NO
RECYCLE
DIMENSIONS
IF DESIRED
GTO "0"
END