5.1.10

ANALSDO

CRYOSTAT

STRUCTURAL

DESIGN

ANSALDO

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0. Abstract

The BABAR Cryostat consists of two coaxial cilyndrical shells with two anular end flanges.
The Criostat is both the vacuum chamber than the support structure for the cold mass.

The cold mass is supported by :

- 8 + 8 radial tie rods

- 3 + 3 axial tie rods

the radial tie rods are fixed to the outer cylinder while the axial tie rods are fixed at the end flanges.

Cryostat dimensions :

Inner diameter :	2840 mm
Outer diameter :	3540 mm
Length :	3850 mm

Cryostat characteristics :

Weigth :	2.5 tons
Material :	Aluminium Alloy Al 5083-0

1. Preliminary Design according to ASME VIII

For estabilishing the starting thicknesses we used the ASME VIII Rules.
On the basis of "Rules for Construction of Pressure Vessel " Div.1 we use the Rule of Par.UG-28 "Thickness of shells and tubes under External Pressure".

For the inner cylinder we fixed the Design External Pressure at 0.2 bar(g) keeping into account that from the inner side acts the atmosperical pressure.
While for the outer cylinder we fixed the Design External Pressure at 1 bar(abs).

Inner Cylinder

Using a starting thickness of 8 mm we evaluated the following ratios :
Do/t = 2840/8 = 355 (Do/t>10) and L/Do = 3850/2840 = 1.3556.

Using the diagramma UGO-28.0 we obtained the Coefficent A= 0.00015
Because this value falls on the left side of the diagram ANF-28.23 the formula for the maximum allowable pressure is given by the relation :

$$Pa = (2 * A * E) / (3 * Do/t) = 0.207 \text{ bar}$$

where:

E = Young Modulus of Al 5083-0 at R.T.

Outer Cylinder

Using a starting thickness of 20 mm we evaluate the following ratios :
Do/t = 3540/20 = 177 (Do/t>10) and L/Do = 3850/3540 = 1.0876.

Using the diagramma UGO-28.0 we obtain the Coefficents A= 0.0005 and B = 2500.
In this case the relation for the maximum allovable pressure is :

$$Pa = (4 * B) / (3 * Do/t) = 1.3 \text{ bar}$$

End Flanges

Using the relation contained into Par. UG-34 "Unstayed flat heads and covers" the minimum thichness required is 10 mm.

So the minimum thicknesses required to verify the ASME VIII Rules (for only pressure load) are :

- inner cilinder	8	mm
- outer cilynder	20	mm
- end flanges	10	mm

2. Al 5083-0 Mechanical Characteristics

The Aluminium alloy is Al 5083-0.
The mean characteristics at room temperature are :

- Young Modulus	72 GPa
- Poisson ratio	0.33
- Yield Strength	120 MPa
- Allowable Stress (ASME VIII Table UNF-23.1)	69 MPa (10.000 psi)

3. F.E.M. Model

The F.E.M. Model has been performed using the ANSYS Code Rev.4.4a.
The element used is n.o 63 "Elastic Quadrilateral Shell".
This element has both bending and membrane capabilities.
Both in plane and normal loads are permitted.
The element has six degrees of freedom at each node :
translation in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes.

The quadrilateral shell has options for variable thicknesses.
In output the Code gives :

- Stress Intensity and Equivalent Stress SI and SIGE
- Top , Middle & Bottom combined Membrane & Bending stresses Sx, Sy, Sz, and Sxy

4. Cryostat dimensions

The cryostat main dimensions are :

Inner diameter :	2840 mm
Outer diameter :	3540 mm
Length :	3850 mm

and keeping into account the further loads reported in Par.5 the shells thicknesses are :

Inner cylinder	10 mm
Outer cylinder (*)	25 mm
End flanges	40 mm

(*) for a length of 250 mm (at each end) the outer cylinder has been reinforced with two rings for a total thickness of 50 mm
(See Fig.0)

5. Loads

A) BASIS LOADS

1- External pressure	1.013	bar
2- Cryostat weigth	2.5	tons
3- Cold Mass Weigth	7.8	tons (Fp)

B) MISALIGMENT FORCES

1- Max Axial Misaligment	25	tons
2- Max Radial Misaligment	20	tons

C) EARTHQUAKE EFFECT LOADS

1- Vertical Earthquake 1.6 g (1.6 x 7.8 = 12.5 tons)

2- Horizontal Earthquake 0.2 g (0.2 x 7.8 = 1.6 tons)

6. Load Situations analized

Five cases have been analized :

1 - Normal Operation (Zero Misalignment , No Earthquake)

2 - Max. Radial and Axial misalignment (Radial Dis. Vertically acting)

3 - Max. Earthquake loads plus Max Radial & Axial misaligment (Radial Dis.Vertically acting)

4 - Max..Earthquake loads plus Max Radial & Axial misaligment (Radial Dis. Horizontally acting)

NOTE : in the previous cases we considered the cryostat supports fixed at both extremities

5 - some case than 3 except one side supports simply supported

Here below the terms meaning is reported :

Fx = Total horizontal force

Fy = Total vertical force

Fp = Cold mass weigth

Fax = Total axial force

Fda = Total axial misaligment

Fdr = Total radial misaligment

Fta = Total eartquake effect for axial direction

Ftr = Total earthquake effect for radial direction

Case 1 (file BAB1)

Fy = Fp = 7.8 t → Fy/8 ≈ 1 t

46 degrees tie-rods Force Component

Fy/8 = 1 t 0.45 Fy/8 = 0.45 t

13 degrees tie-rods Force Component

Fy/8 = 1 t 0.73 Fy/8 = 0.73 t

Case 2 (File BAB2)

Fy = Fp + Fdr = 7.8 + 20 = 27.8 t → Fy/8 = 3.475 t

Fax = Fda = 25 t → Fax/3 = 8.33 t

46 degrees tie-rods Force Component

Fy/8 = 3.475 t 0.45 Fy/8 = 1.56 t

13 degrees tie-rods Force Component

Fy/8 = 3.475 t 0.73 Fy/8 = 2.54 t

Case 3 (File BAB3)

Fy = Fp + Fdr + Ftv = 7.8 + 20 + 12.5 = 40.3 t → Fy/8 = 5.04 t

Fax = Fda + Fta = 25 + 1.6 = 26.6 t → Fax/3 = 8.85 t

46 degrees tie-rods Force Component

Fy/8 = 5.04 t 0.45 Fy/8 = 2.27 t

13 degrees tie-rods Force Component

Fy/8 = 5.04 t 0.73 Fy/8 = 3.68 t

Case 4 (File BAB4)

Fy = Fp + Ftv = 7.8 + 12.5 = 20.3 t → Fy/8 = 2.535 t

Fx = Fdr + Fta = 20 + 1.6 = 21.6 t → Fx/8 = 2.695 t

Fax = Fda + Fta = 25 + 1.6 = 26.6 t → Fax/3 = 8.85 t

46 degrees tie-rods Force Component

Fy/8 = 2.535 t 0.45 Fy/8 = 1.14 t Fx/8 = 2.695 t 2.25 Fx/8 = 6.06 t

13 degrees tie-rods Force Component

Fy/8 = 2.535 t 0.73 Fy/8 = 1.85 t Fx/8 = 2.695 t 1.38 Fx/8 = 3.72 t

Case 5 (file BAB7)

the same load case than BAB3 except the cryostat support that are only locked in the vertical direction. (see Fig.1 and Fig.2)

7. Results

The F.E.M. analisys gives the following results :

File	BAB1	BAB2	BAB3	BAB4	BAB7
INNER CYLINDER					
Stress Intensity (MPa)	20	26	27	22	27
Hoop Stress (MPa)	18	20	21	21	22
Axial stress (MPa)	10	20	21	13	20
Max. radial displ. (mm)	0.60	0.71	0.73	0.63	0.47
OUTER CYLINDER					
Stress Intensity (MPa)	13	36	38	37	40
Hoop Stress (MPa)	6	10	13	14	12
Axial stress (MPa)	10	28	30	25	32
Max. radial displ. (mm)	-0.25	-0.26	-0.28	-0.33	-0.27
END FLANGES					
Stress Intensity (MPa)	19	69(*)	70(*)	65(*)	73(*)
Hoop stress (MPa)	17	60(*)	62(*)	63(*)	66(*)
Max. axial displacement (mm)	0.15	0.33	0.34	0.21	0.41

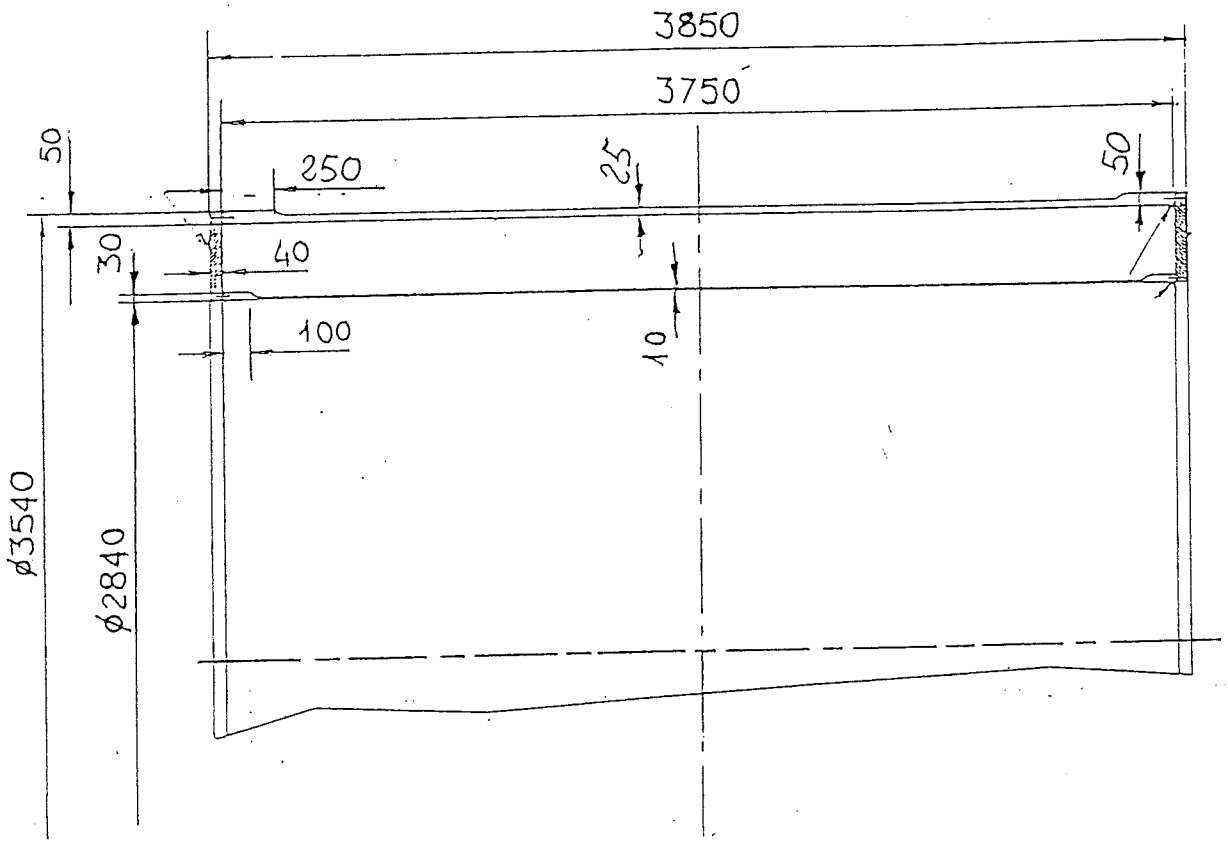
(*) these values are punctual i.e. are concentrated in the point of application of the axial tie rod and don't represent the realty of the rod anchorage.

Note : for the displacements the minus sign means that the displacement is toward the coil axis

In Annex 1 are reported the plots referred to the Case 3 (File BAB3) and Case 5 (File BAB7)

8. Conclusions

Scope of this Report is to evaluate the BABAR Cryostat behaviour under loads due both to the normal operation, to maximum radial & axial misaligment and to eartquake effects.
With the thicknesses used the Cryostat structure is able to withstand to the load applied.



Cryostat Main Dimensions

Fig.0

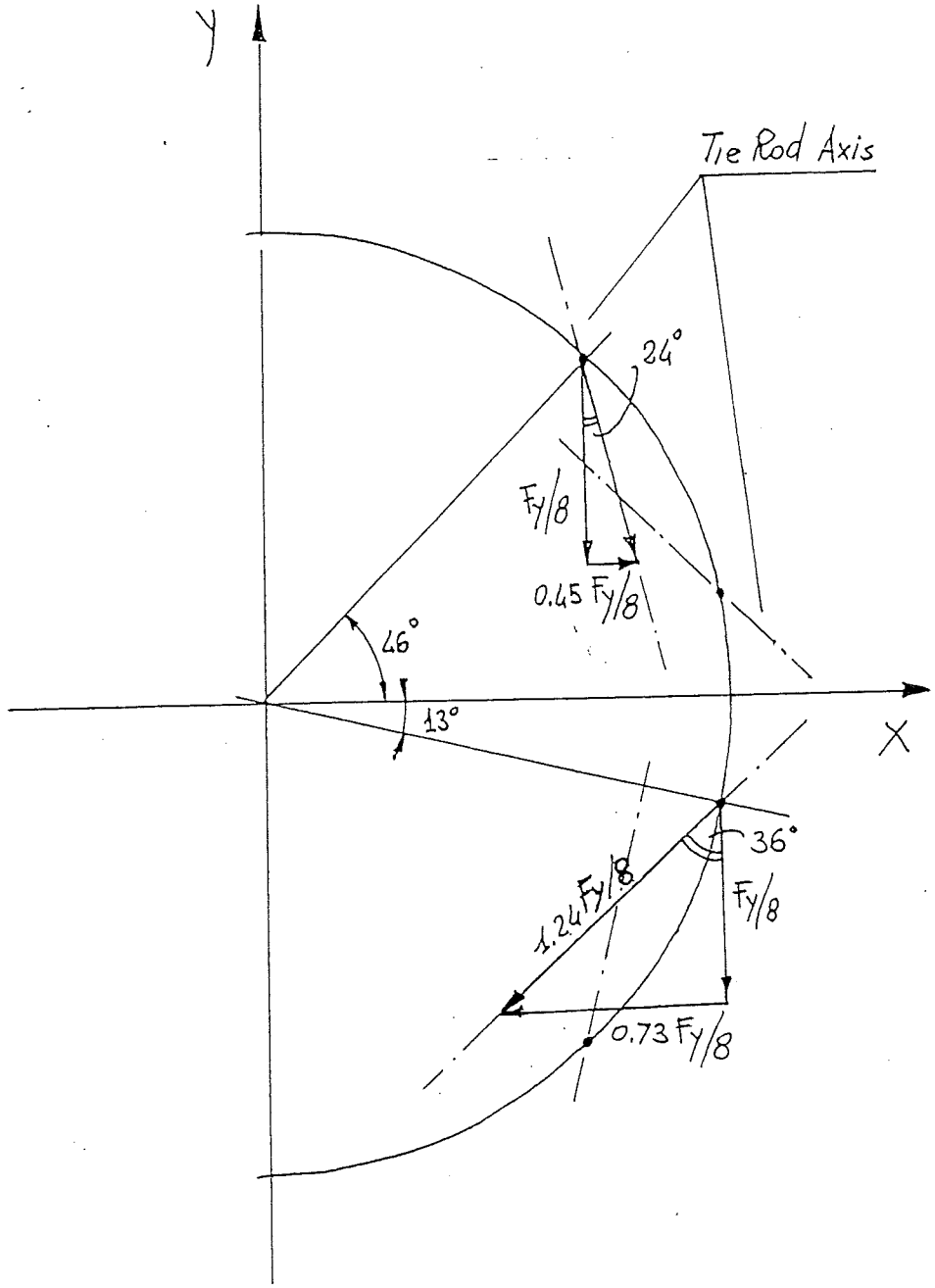


Fig.1

Tie Rods Forces distribution (due to cold mass weigth, earthquake and radial misalignment vertically acting

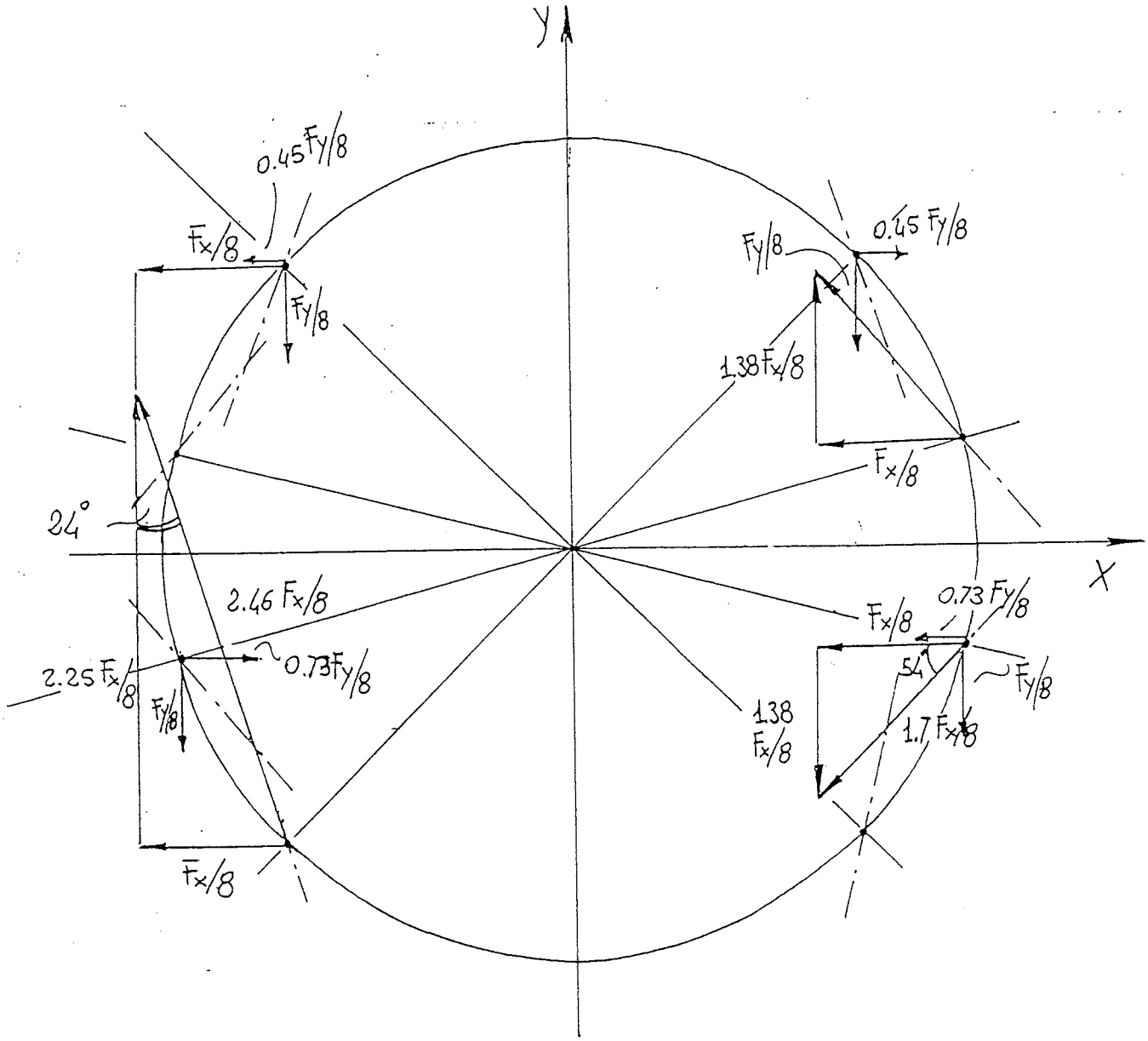
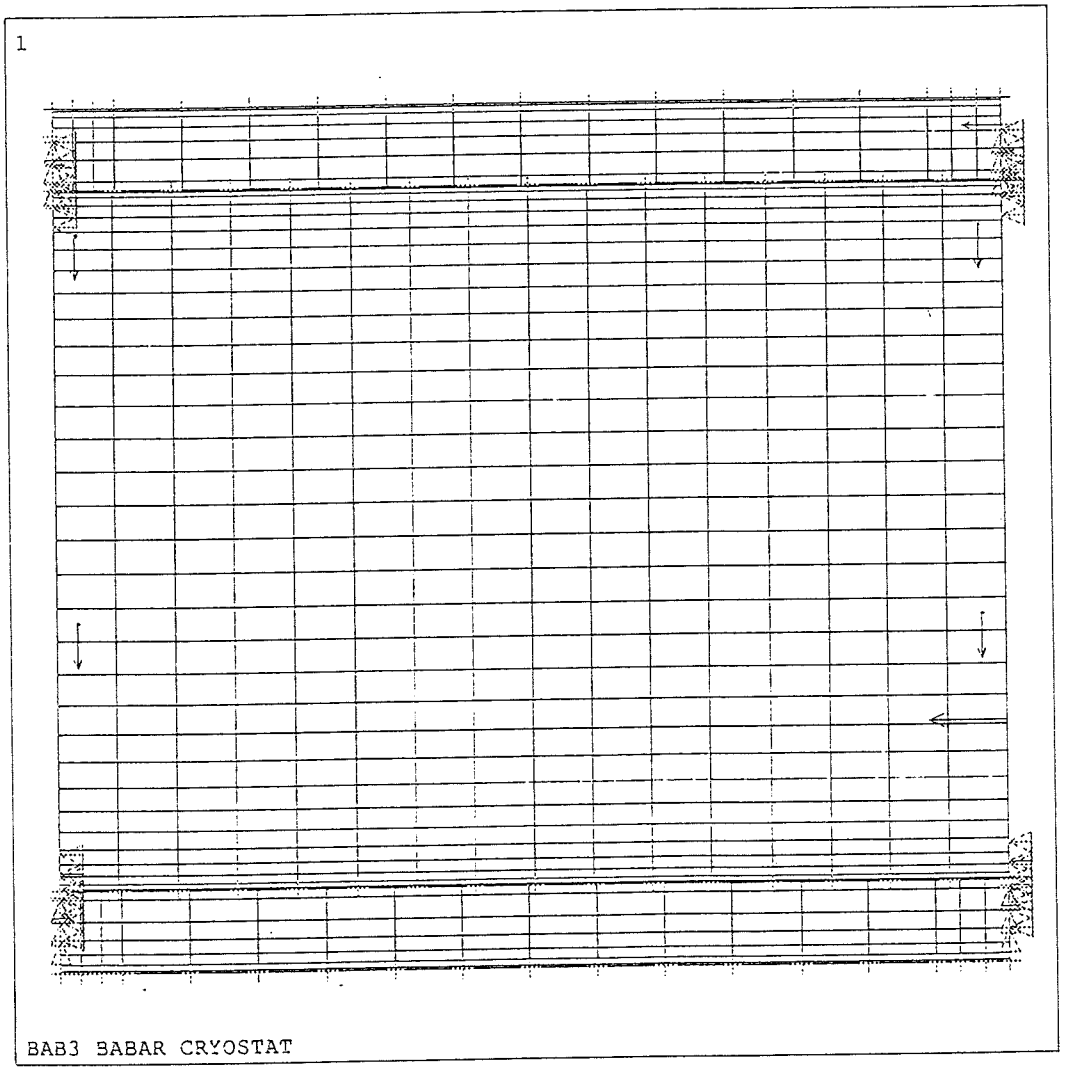


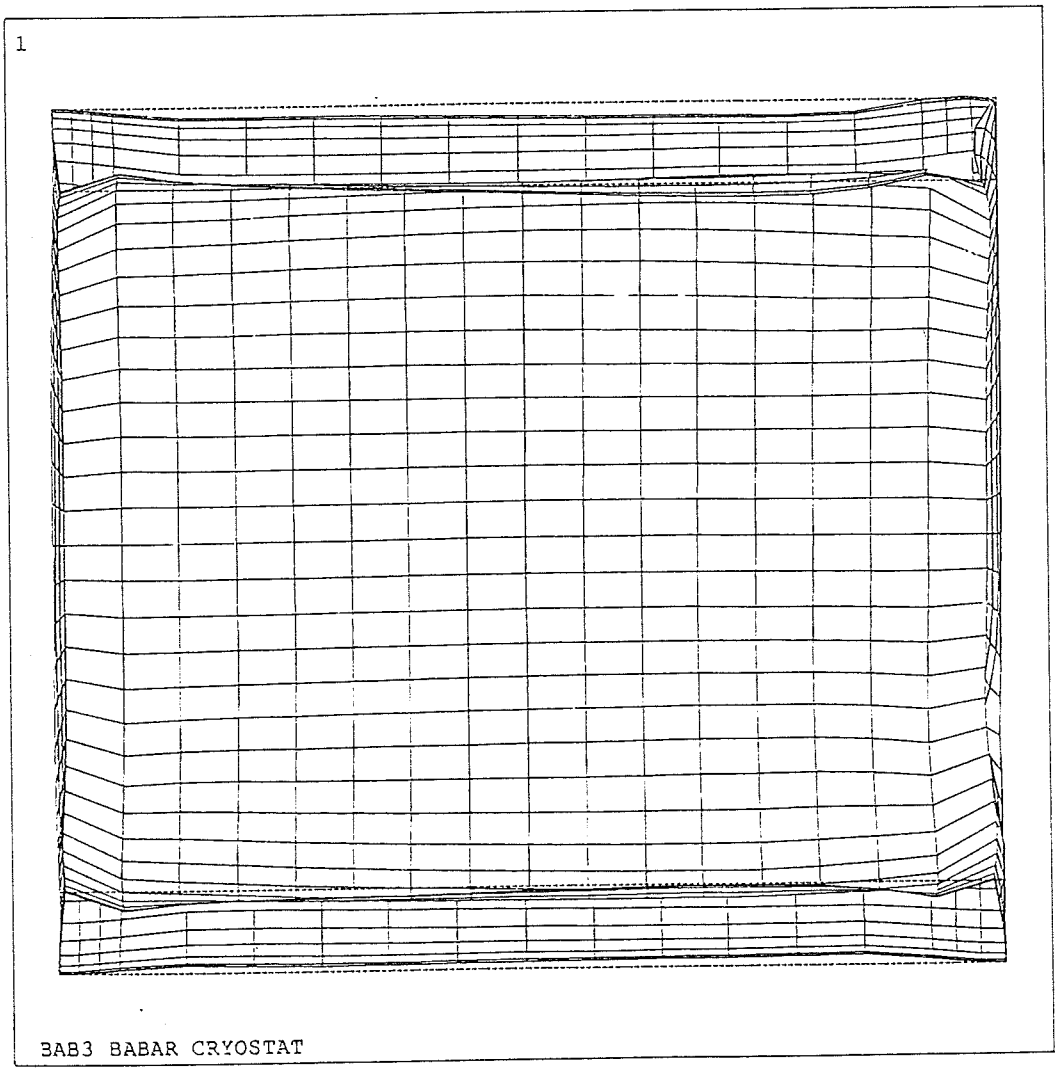
Fig.2

Tie Rods Forces distribution due to the cold mass weigth, earthquake and radial misalignment horizontally acting



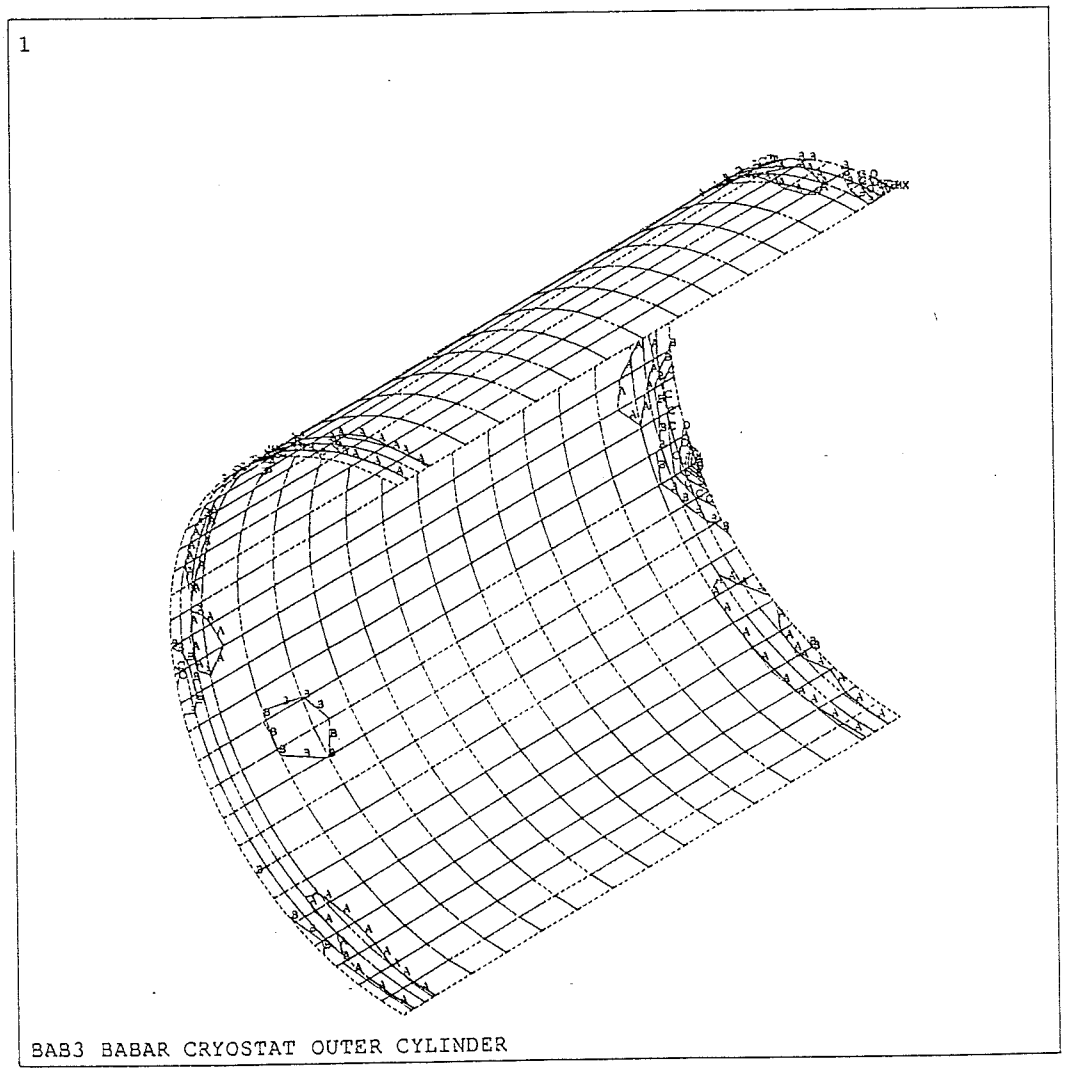
ANSYS 4.4A
AUG 13 1996
17:45:43
PLOT NO. 2
PREP7 ELEMENTS
TYPE NUM
TOLS
FORC

XV =1
DIST=2.129
XF =-0.87875
ZF =1.935
PRECISE HIDDEN



ANSYS 4.4A
AUG 13 1996
17:50:39
PLOT NO. 1
POST1 DISPL.
STEP=1
ITER=2
DMX =0.742E-03
ERPC=0

DSCA=286.959
XV =1
DIST=2.129
XF =-0.87875
ZF =1.935
PRECISE HIDDEN



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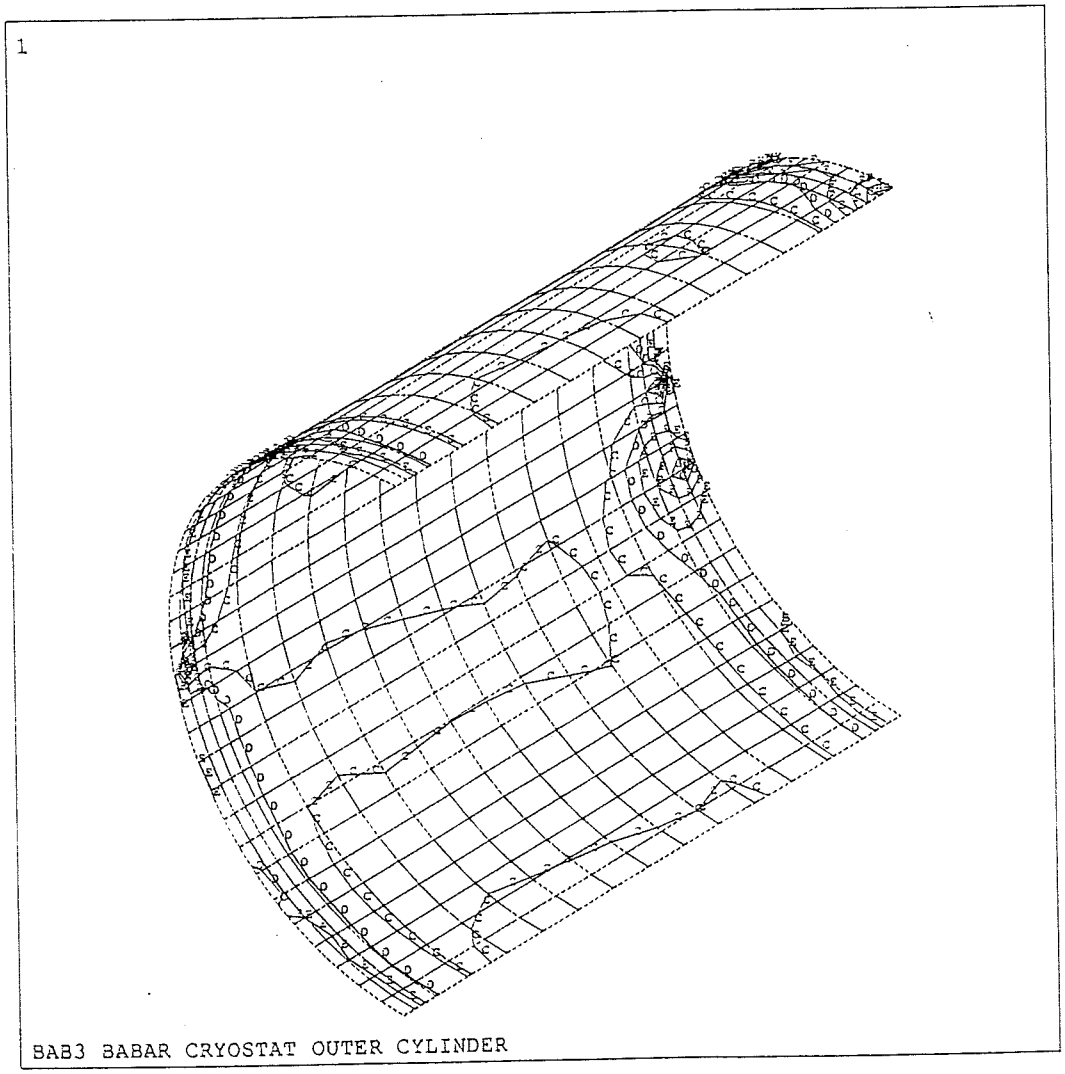
17:51:15
PLOT NO. 4
POST1 STRESS
STEP=1
ITER=2
SIGE (AVG) [Pa]
BOTTOM
DMX =0.742E-03
SMN =0.141E+07
SMX =0.384E+08
SMXB=0.438E+08

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =0.346E+07
B =0.757E+07
C =0.117E+08
D =0.158E+08
E =0.199E+08
F =0.240E+08
G =0.281E+08
H =0.322E+08
I =0.363E+08



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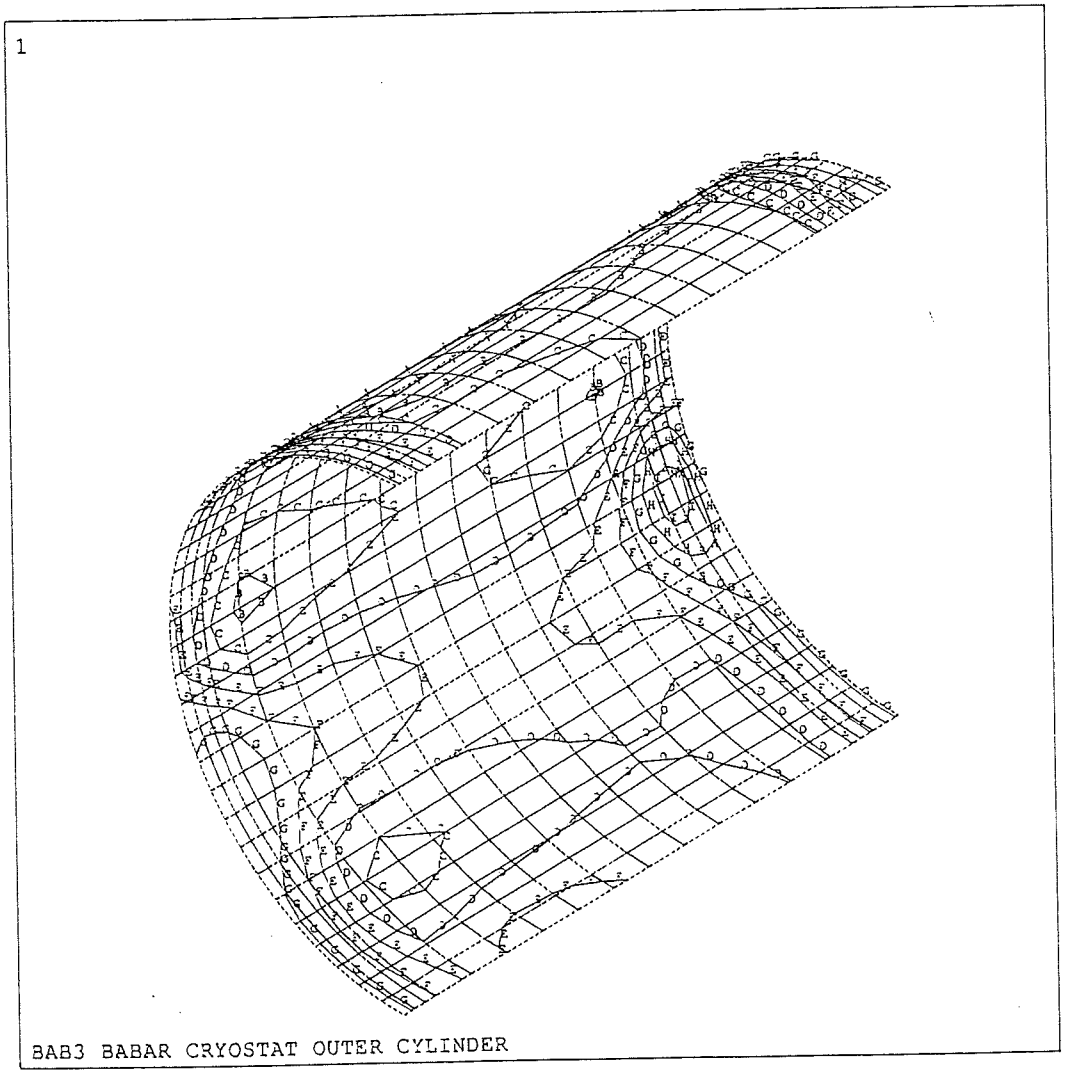
17:51:26
PLOT NO. 5
POST1 STRESS
STEP=1
ITER=2
SY (AVG) [Pa]
TOP
CSYS=11
DMX =0.742E-03
SMN =-0.144E+08
SMNB=-0.199E+08
SMX =0.126E+08
SMXB=0.199E+08

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =-0.129E+08
B =-0.993E+07
C =-0.692E+07
D =-0.391E+07
E =-903412
F =0.211E+07
G =0.511E+07
H =0.812E+07
I =0.111E+08



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17:51:41
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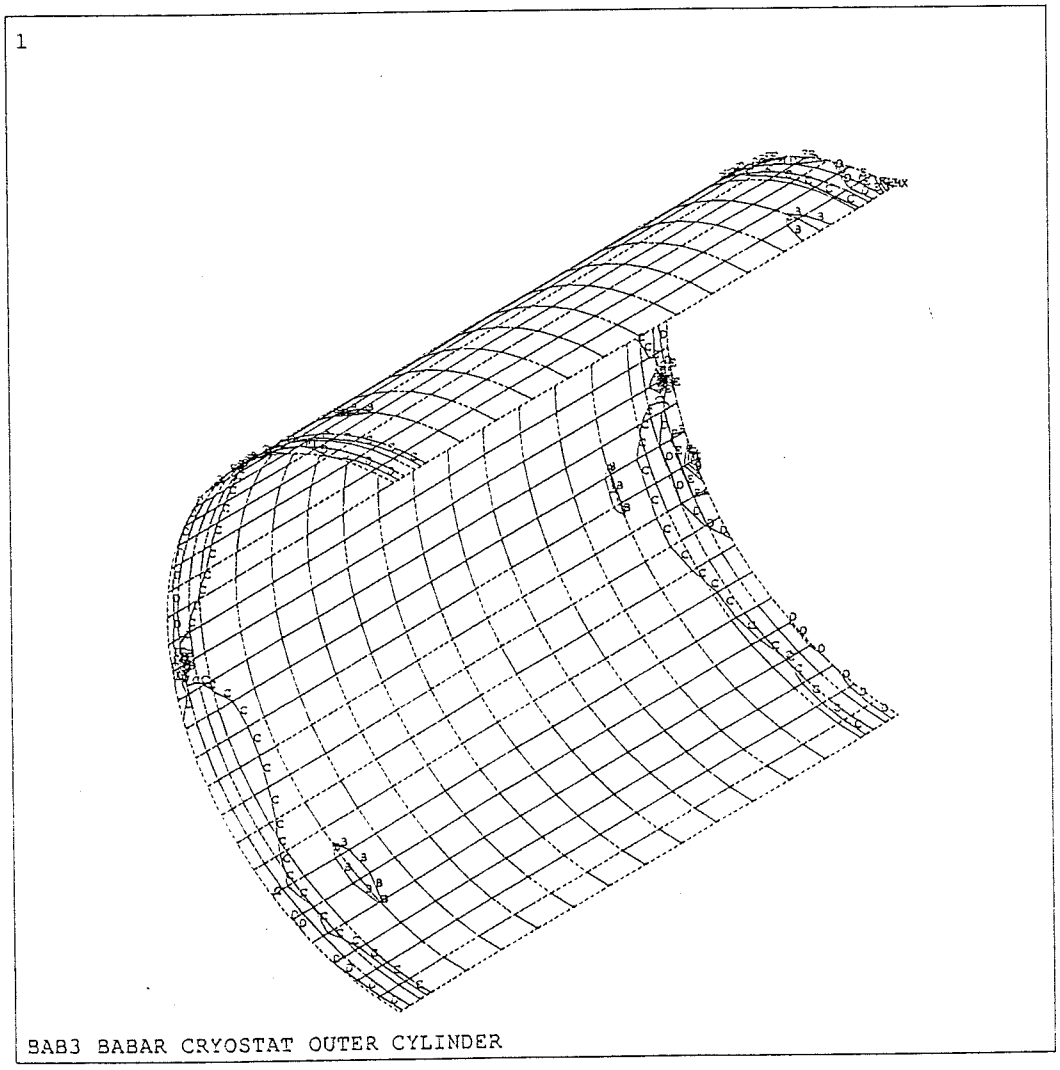
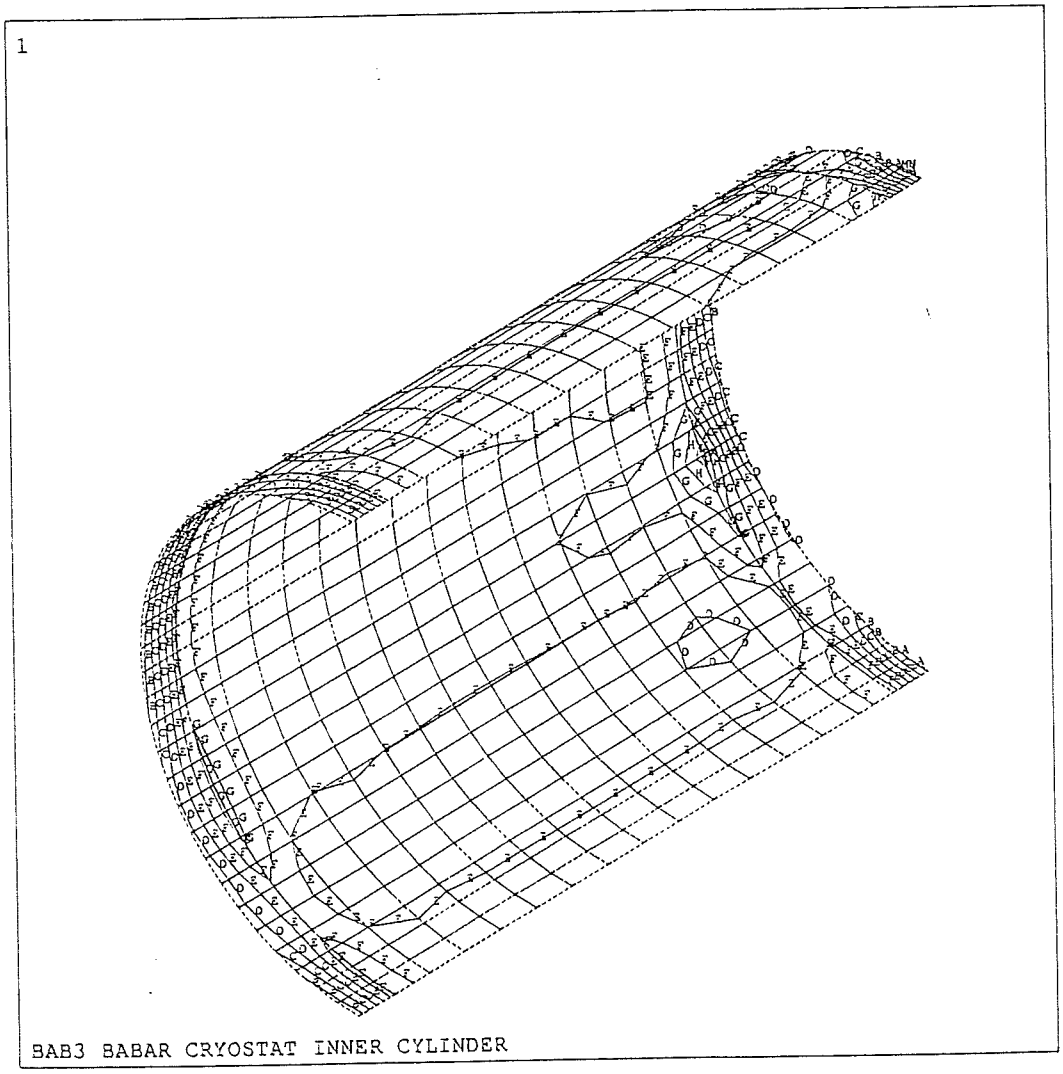
STEP=1
ITER=2
UX [m]
CSYS=11
DMX =0.742E-03
SMN =-0.275E-03
SMX =0.988E-04

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =-0.254E-03
B =-0.212E-03
C =-0.171E-03
D =-0.129E-03
E =-0.879E-04
F =-0.464E-04
G =-0.491E-05
H =0.366E-04
I =0.781E-04



ANSYS 4.4A
AUG 13 1996
17:51:31
PLOT NO. 6
POST1 STRESS
STEP=1
ITER=2
SZ (AVG) [Pa]
TOP
CSYS=11
DMX =0.742E-03
SMN =-0.119E+08
SMNB=-0.173E+08
SMX =0.298E+08
SMXB=0.352E+08

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =-0.958E+07
B =-0.495E+07
C =-315260
D =0.432E+07
E =0.895E+07
F =0.136E+08
G =0.182E+08
H =0.228E+08
I =0.275E+08



ANSYS 4.4A
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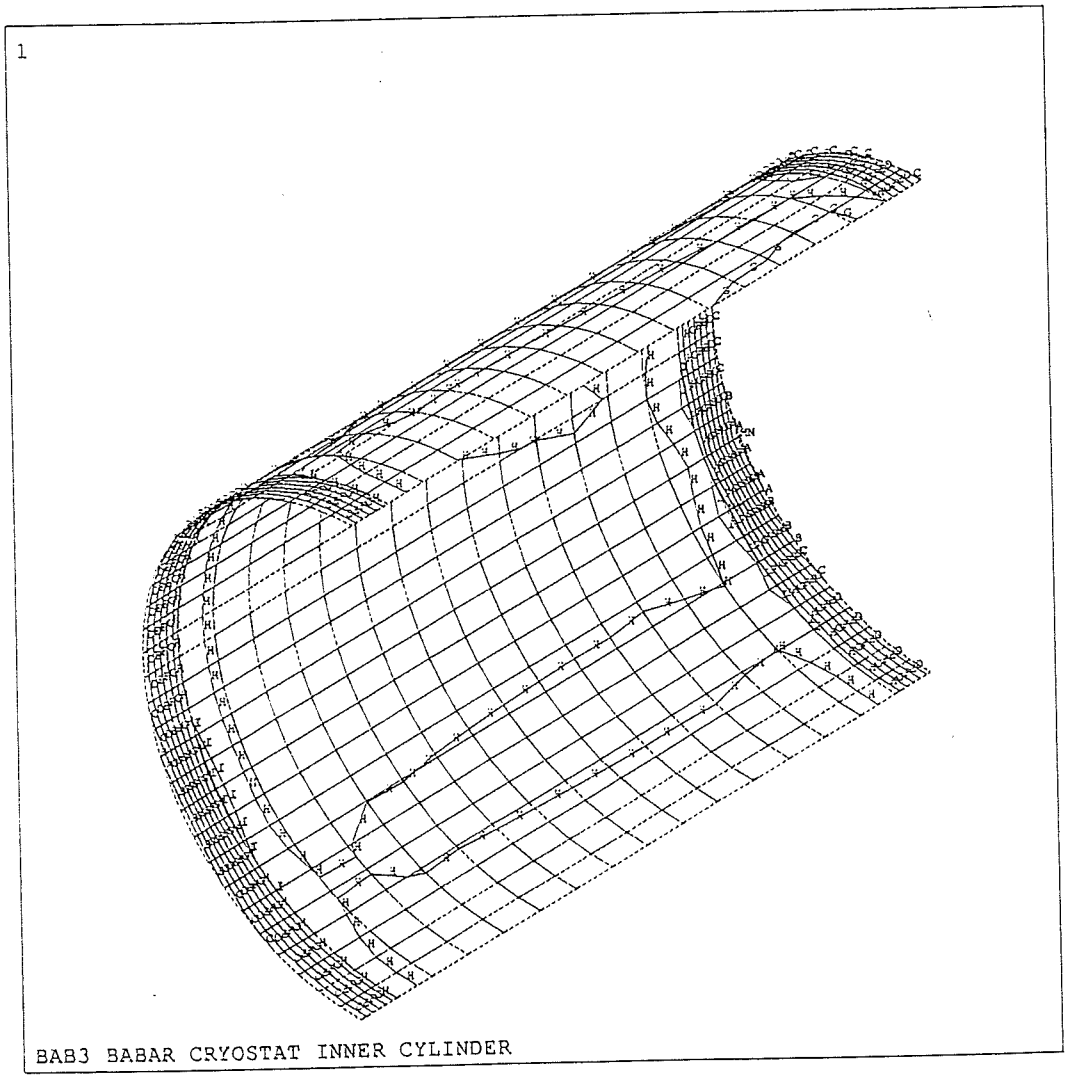
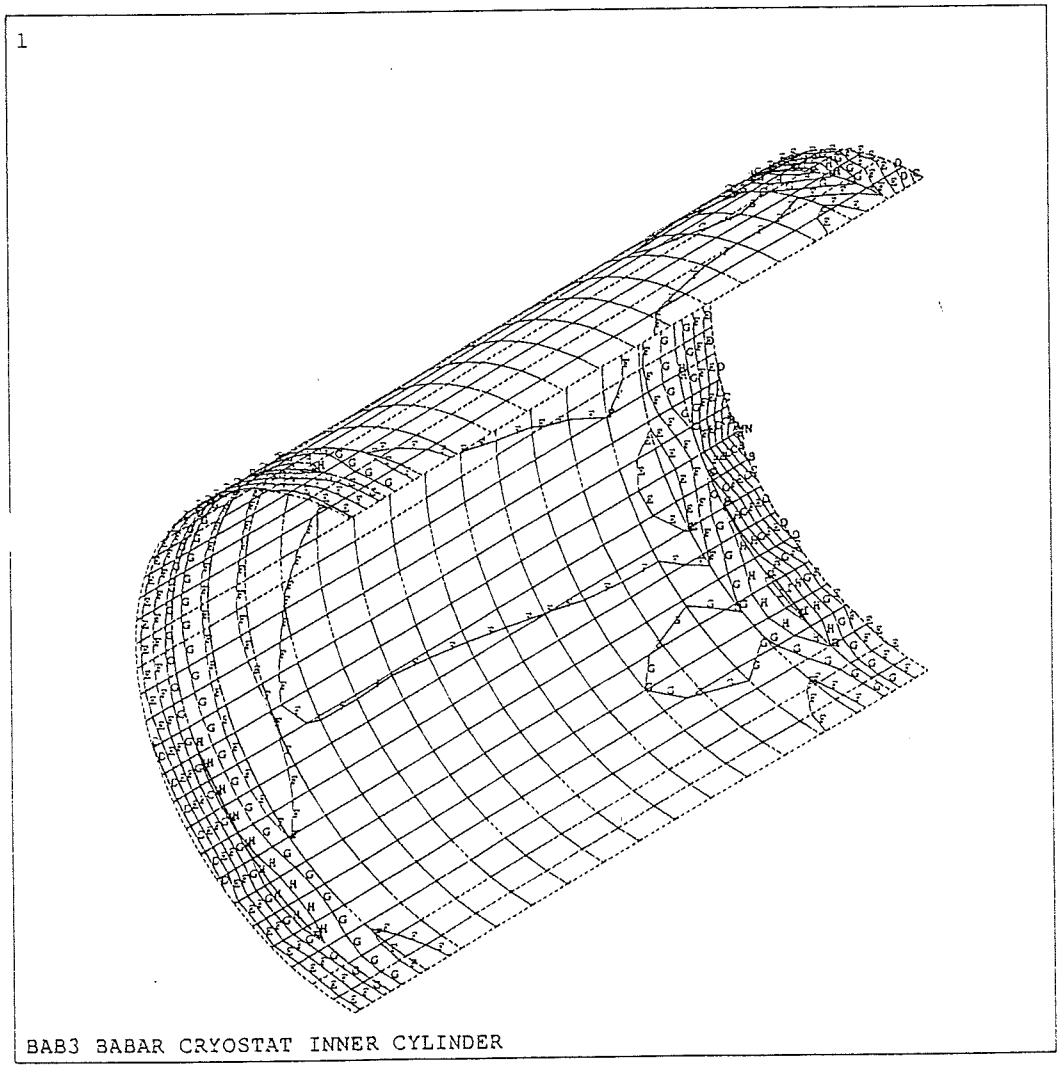
17:52:12
PLOT NO. 12
POST1 STRESS
STEP=1
ITER=2
SIGE (AVG) [Pa]
BOTTOM
DMX =0.742E-03
SMN =0.206E+07
SMNB=251324
SMX =0.268E+08
SMXB=0.290E+08

XV =1
YV =1
ZV =1
DIST=2.469
XF =-0.7125
ZF =1.935
PRECISE HIDDEN
A =0.343E+07
B =0.618E+07
C =0.894E+07
D =0.117E+08
E =0.144E+08
F =0.172E+08
G =0.199E+08
H =0.227E+08
I =0.255E+08



ANSYS 4.4A
AUG 13 1996
17:52:22
PLOT NO. 13
POST1 STRESS
STEP=1
ITER=2
SY (AVG) [Pa]
TOP
CSYS=11
DMX =0.742E-03
SMN =-0.125E+08
SMNB=-0.146E+08
SMX =0.209E+08
SMXB=0.224E+08

XV =1
YV =1
ZV =1
DIST=2.469
XF =-0.7125
ZF =1.935
PRECISE HIDDEN
A =-0.107E+08
B =-0.694E+07
C =-0.322E+07
D =492806
E =0.421E+07
F =0.792E+07
G =0.116E+08
H =0.154E+08
I =0.191E+08



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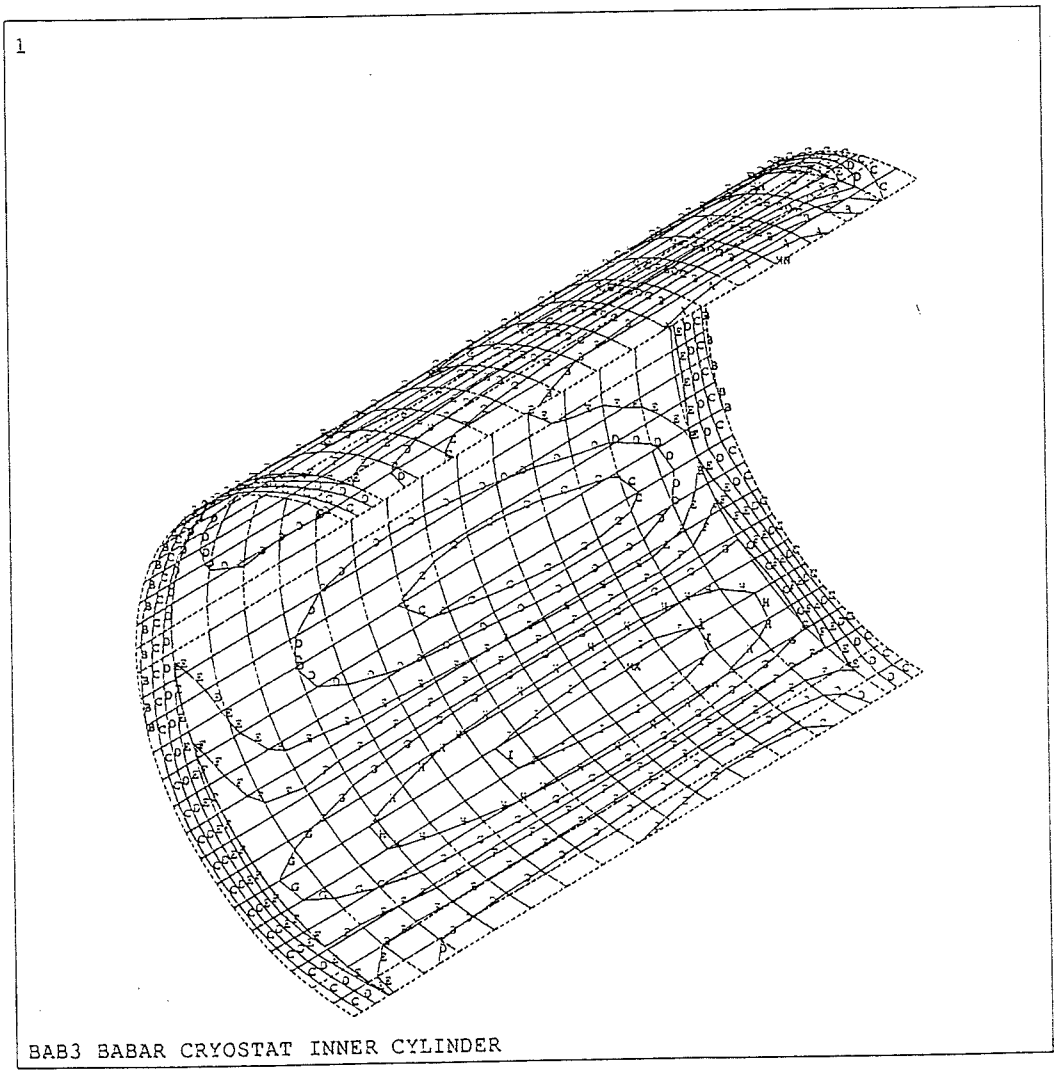
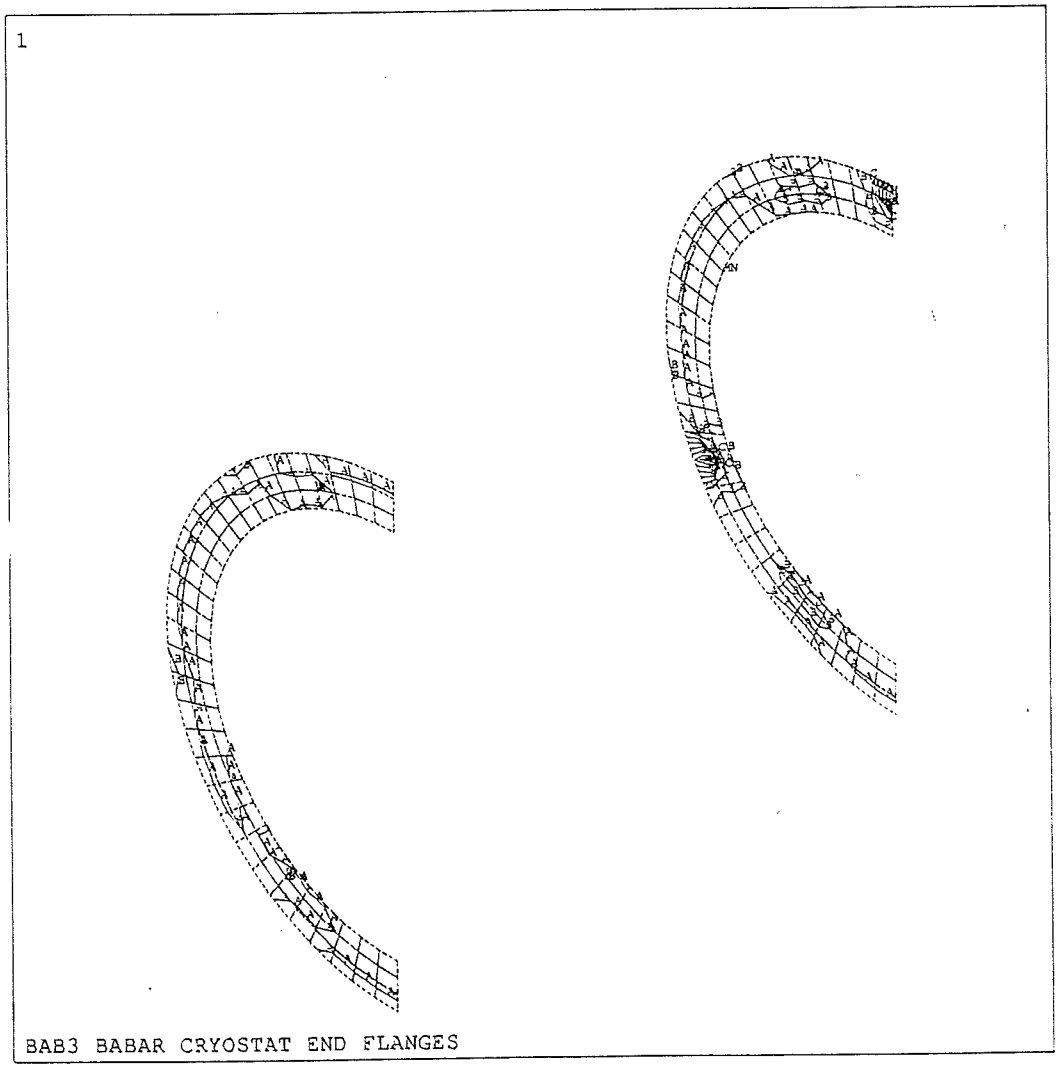
AUG 13 1996
17:52:27
PLOT NO. 14
POST1 STRESS
STEP=1
ITER=2
SZ (AVG) [Pa]
TOP
CSYS=11
DMX =0.742E-03
SMN =-0.211E+08
SMNB=-0.233E+08
SMX =0.115E+08
SMXB=0.127E+08

XV =1
YV =1
ZV =1
DIST=2.469
XF =-0.7125
ZF =1.935
PRECISE HIDDEN
A =-0.193E+08
B =-0.157E+08
C =-0.121E+08
D =-0.847E+07
E =-0.484E+07
F =-0.122E+07
G =0.241E+07
H =0.603E+07
I =0.966E+07



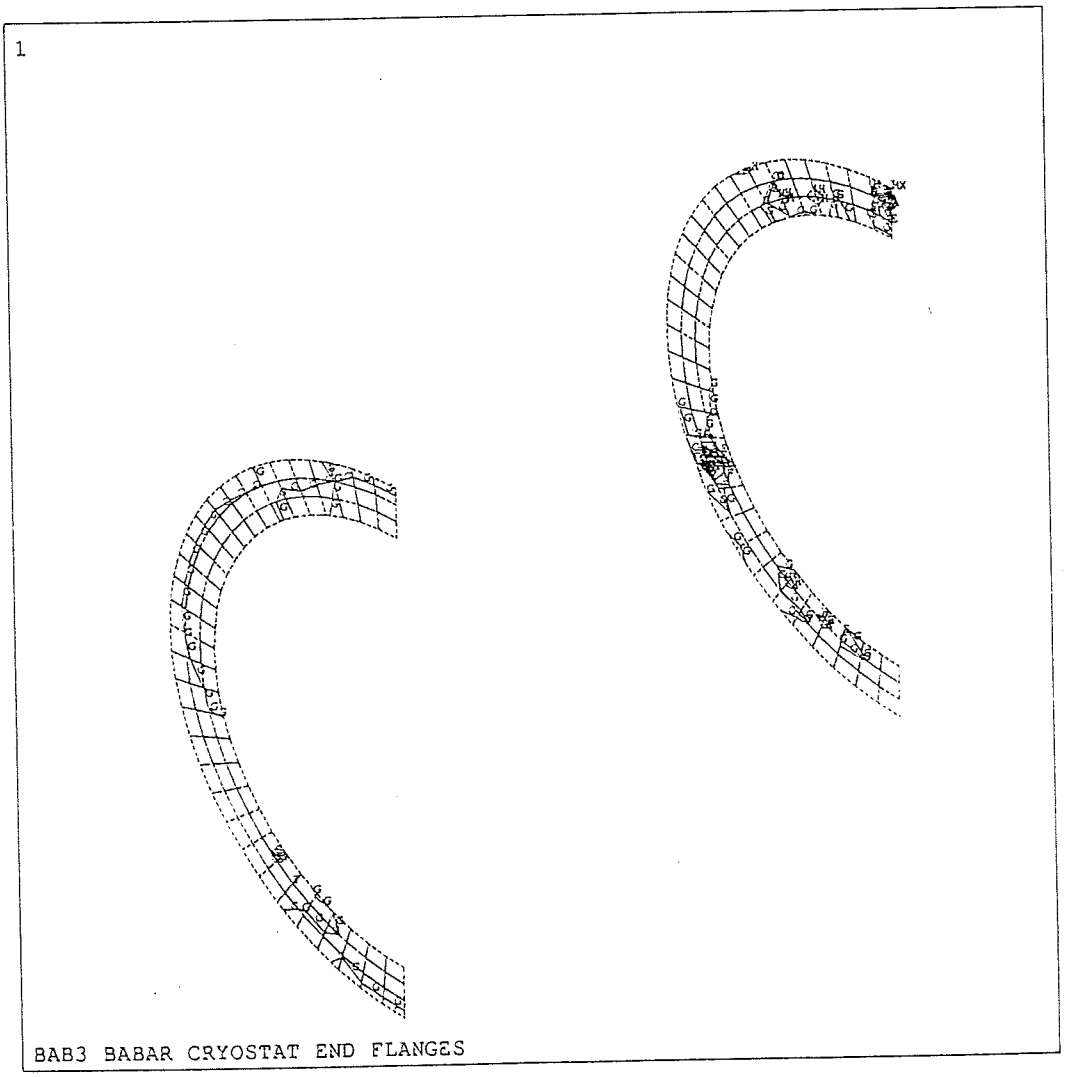
ANSYS 4.4A
AUG 13 1996
17:52:36
PLOT NO. 16
POST1 STRESS
STEP=1
ITER=2
UX [m]
CSYS=11
DMX =0.742E-03
SMN =-0.189E-03
SMX =0.733E-03

XV =1
YV =1
ZV =1
DIST=2.469
XF =-0.7125
ZF =1.935
PRECISE HIDDEN
A =-0.138E-03
B =-0.352E-04
C =0.673E-04
D =0.170E-03
E =0.272E-03
F =0.375E-03
G =0.477E-03
H =0.580E-03
I =0.682E-03



ANSYS 4.4A
AUG 13 1996
17:52:47
PLOT NO. 18
POST1 STRESS
STEP=1
ITER=2
SIGE (AVG)
TOP [Pa]
DMX =0.742E-03
SMN =387277
SMX =0.739E+08
SMXB=0.829E+08

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =0.447E+07
B =0.126E+08
C =0.208E+08
D =0.290E+08
E =0.371E+08
F =0.453E+08
G =0.534E+08
H =0.616E+08
I =0.698E+08



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17:52:58
PLOT NO. 22
POST1 STRESS
STEP=1
ITER=2
SY (AVG) [Pa]
TOP
CSYS=11
DMX =0.742E-03
SMN =-0.657E+08
SMNB=-0.747E+08
SMX =0.224E+08
SMXB=0.329E+08

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =-0.608E+08
B =-0.510E+08
C =-0.412E+08
D =-0.315E+08
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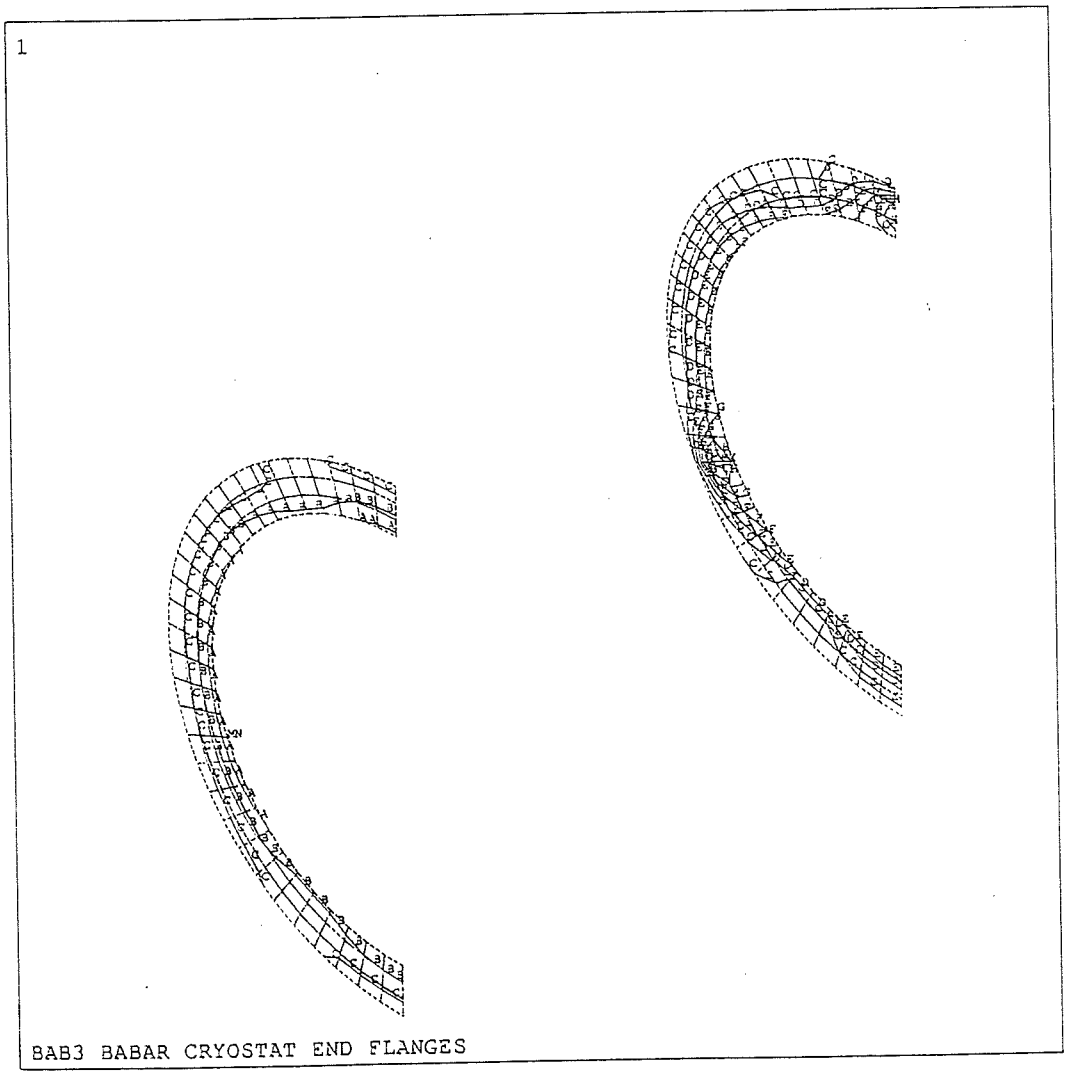
G =-0.209E+07
H =0.770E+07
I =0.175E+08



ANSYS 4.4A
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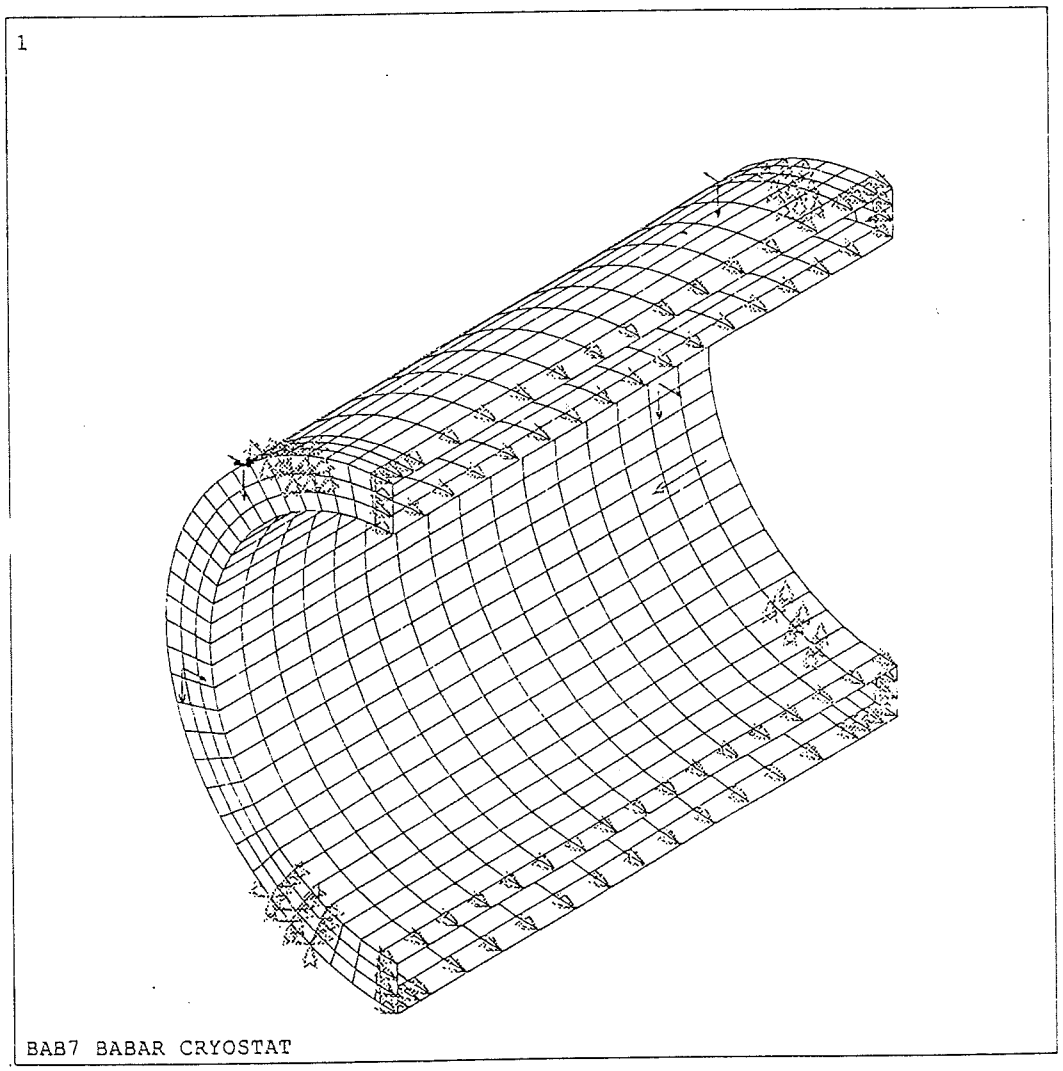
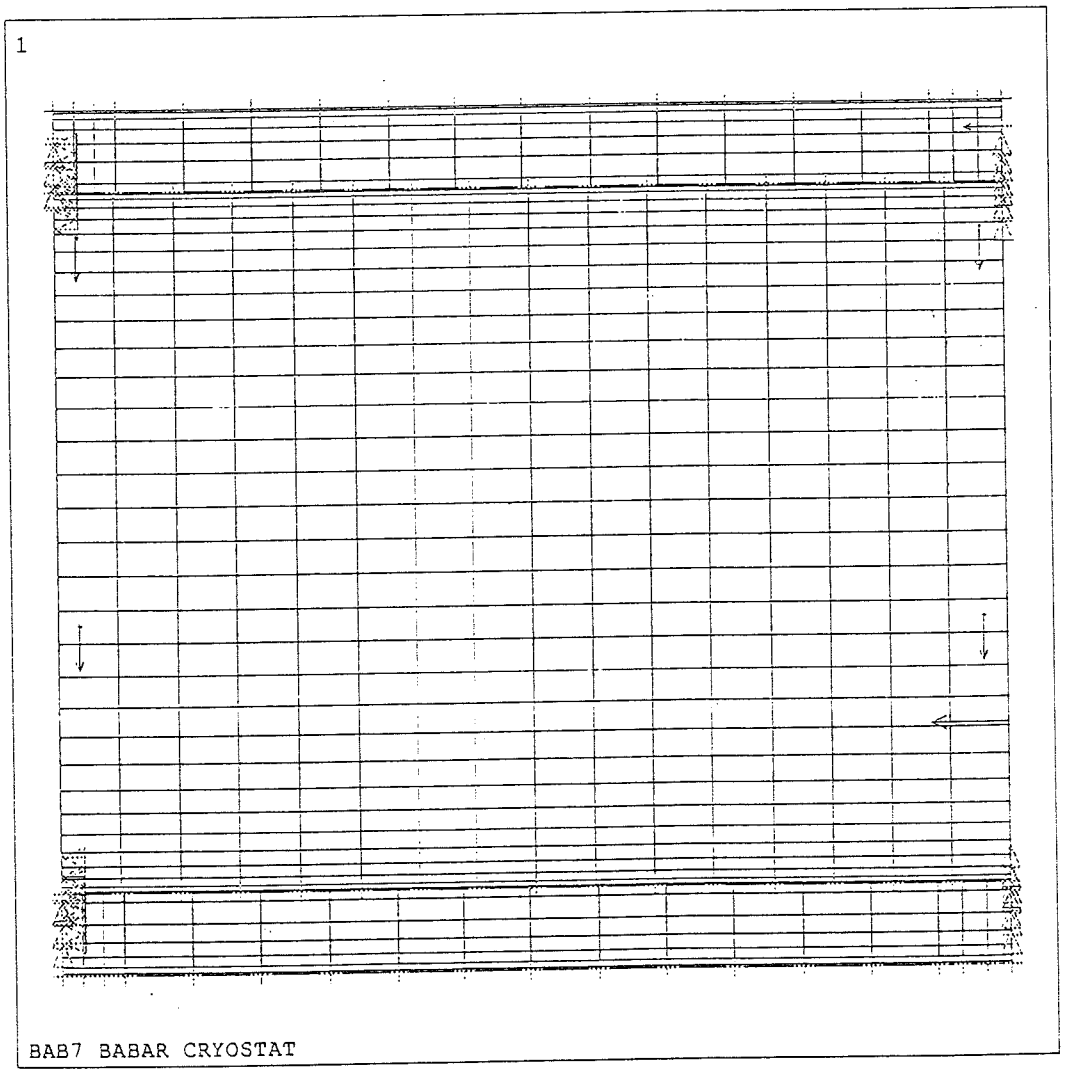
17:53:01
PLOT NO. 24
POST1 STRESS
STEP=1
ITER=2
UZ [m]
CSYS=11
DMX =0.742E-03
SMN =-0.121E-03
SMX =0.342E-03

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =-0.955E-04
B =-0.441E-04
C =0.734E-05
D =0.588E-04
E =0.110E-03
F =0.162E-03
G =0.213E-03
H =0.264E-03
I =0.316E-03



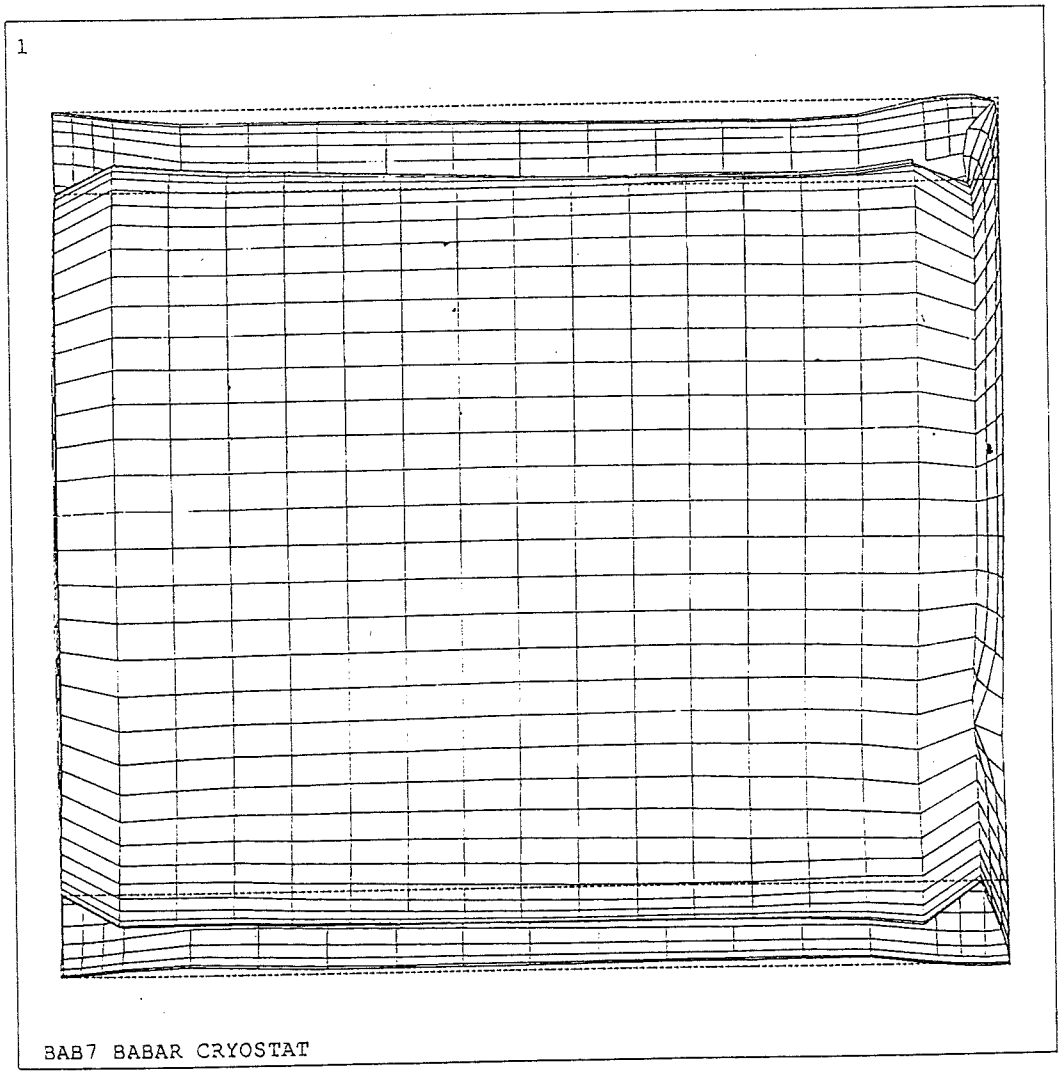
ANSYS 4.4A
SEP 19 1996
14:48:29
PLOT NO. 1
PREP7 ELEMENTS
TYPE NUM
TDIS
FORC

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN



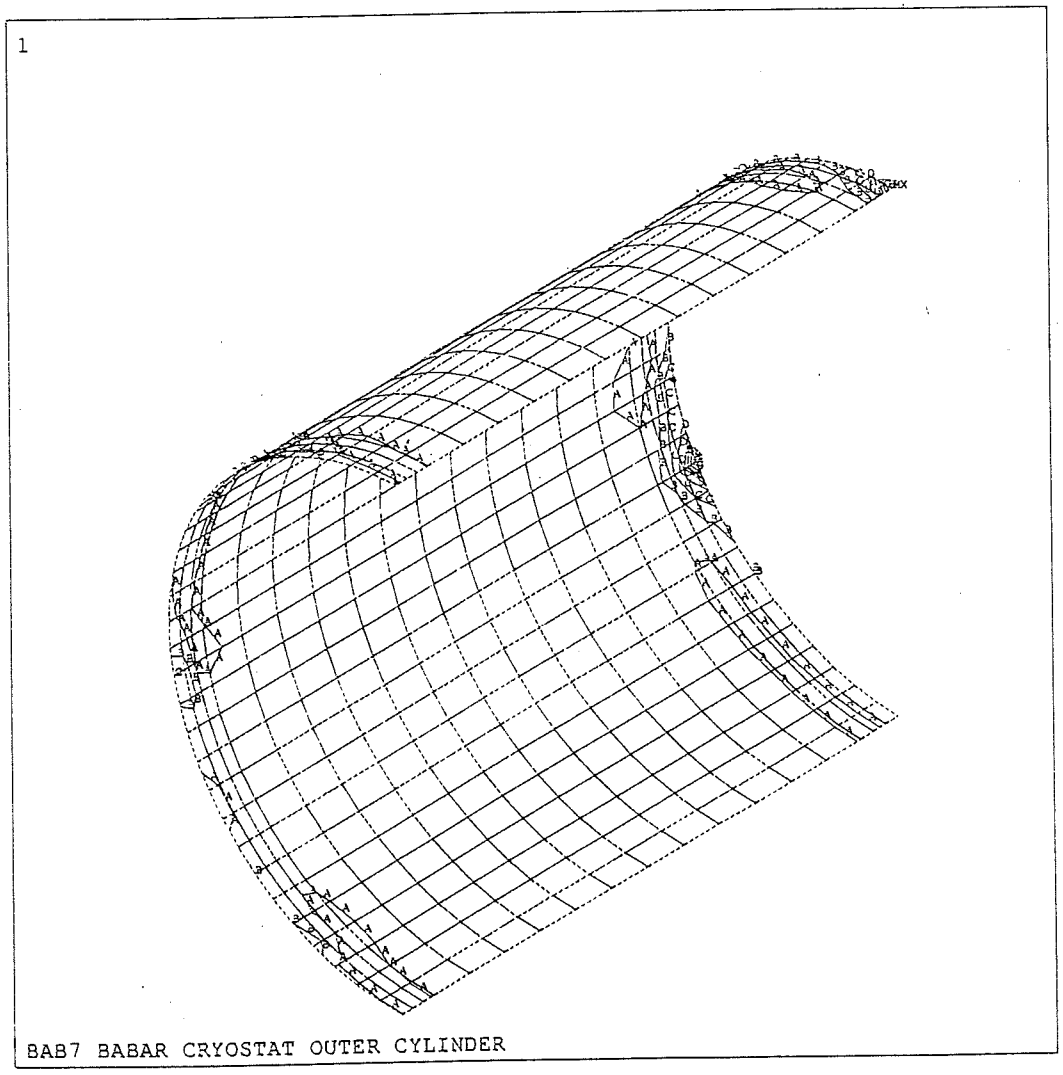
ANSYS 4.4A
SEP 19 1996
14:48:41
PLOT NO. 2
PREP7 ELEMENTS
TYPE NUM
TDIS
FORC

XV =1
DIST=2.129
XF =-0.87875
ZF =1.935
PRECISE HIDDEN



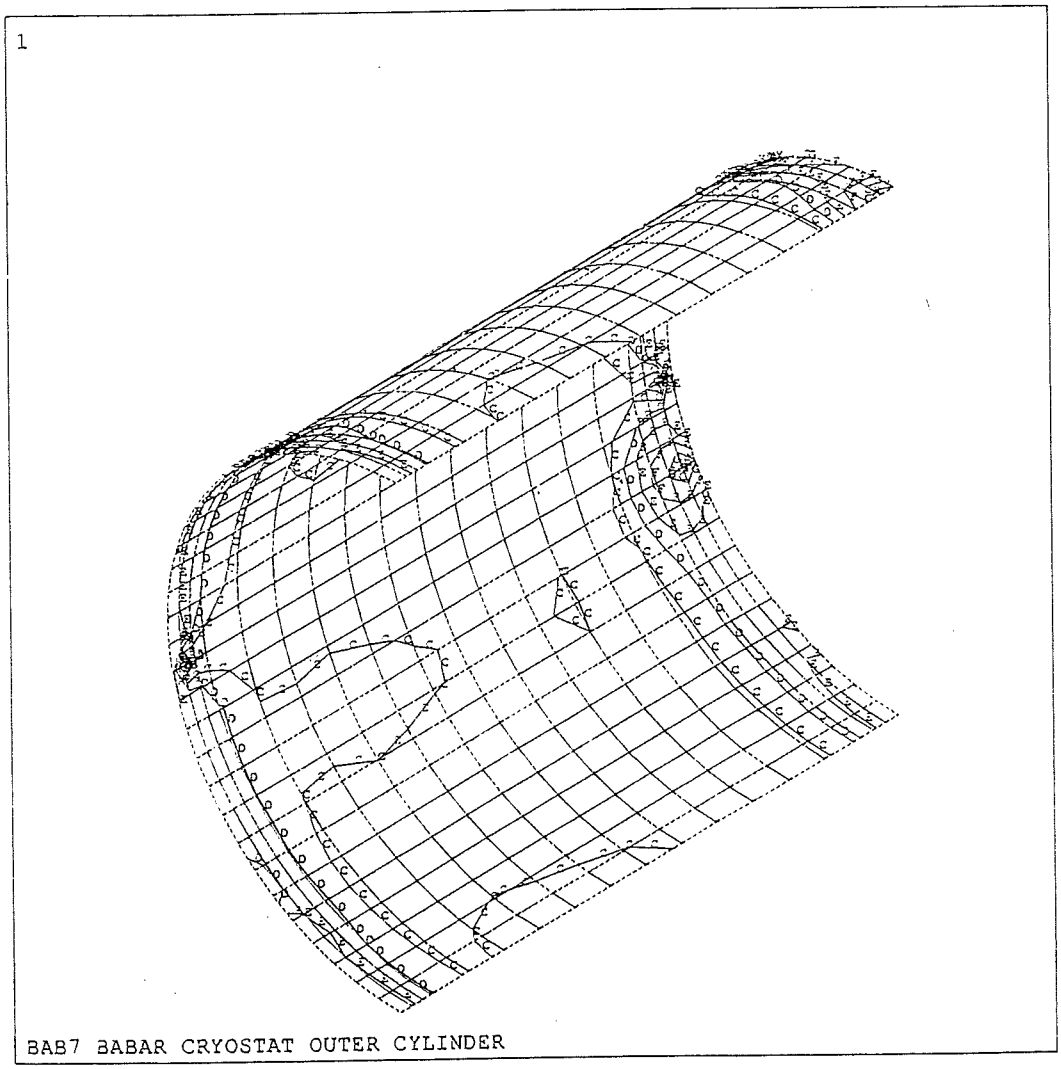
ANSYS 4.4A
SEP 19 1996
14:42:49
PLOT NO. 1
POST1 DISPL.
STEP=1
ITER=2
DMX =0.571E-03
ERPC=0

DSCA=373.054
XV =1
DIST=2.129
XF =-0.87875
ZF =1.935
PRECISE HIDDEN



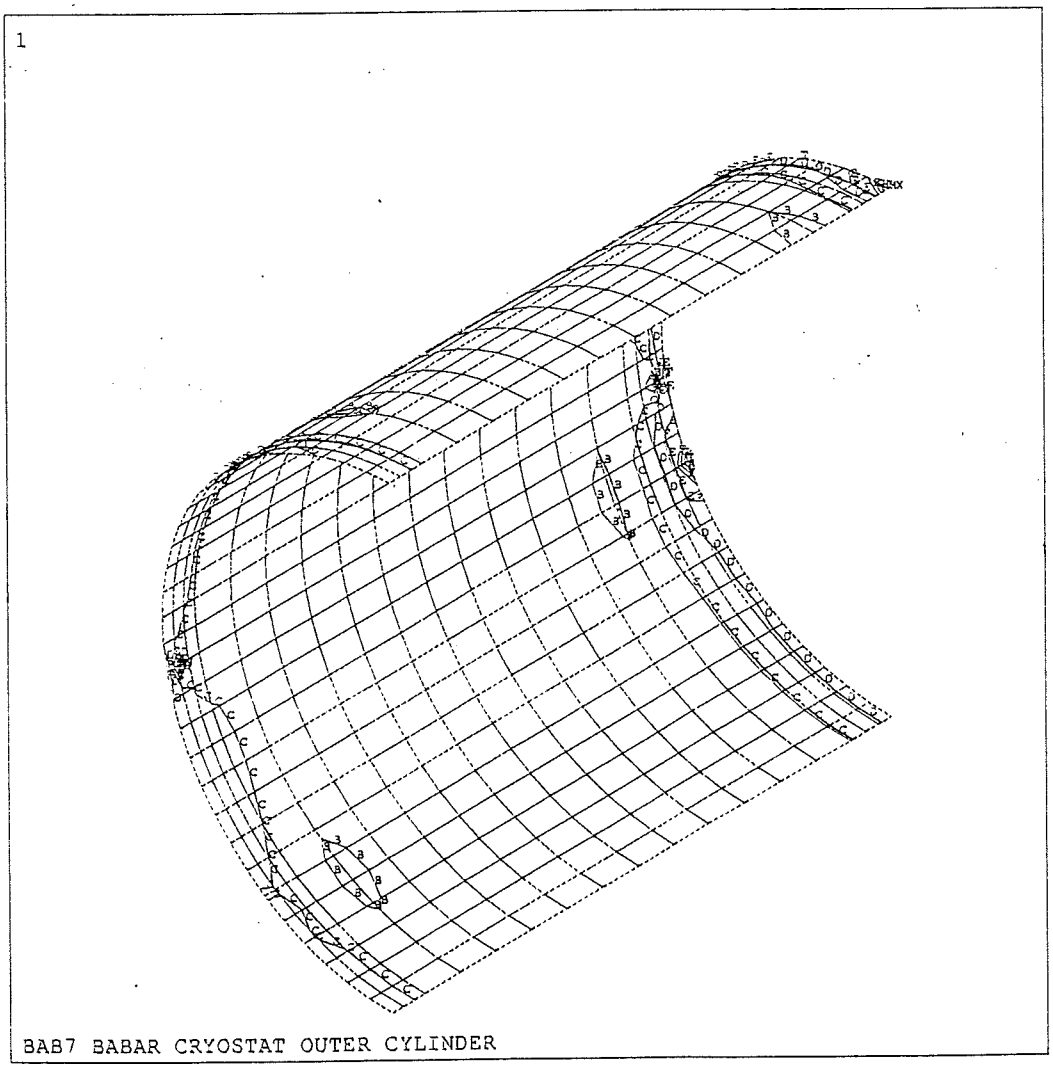
ANSYS 4.4A
SEP 19 1996
14:43:41
PLOT NO. 4
POST1 STRESS
STEP=1
ITER=2
SIGE (AVG) [Pa]
BOTTOM
DMX =0.571E-03
SMN =0.158E+07
SMX =0.398E+08
SMXB=0.452E+08

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =0.370E+07
B =0.795E+07
C =0.122E+08
D =0.165E+08
E =0.207E+08
F =0.250E+08
G =0.292E+08
H =0.335E+08
I =0.377E+08



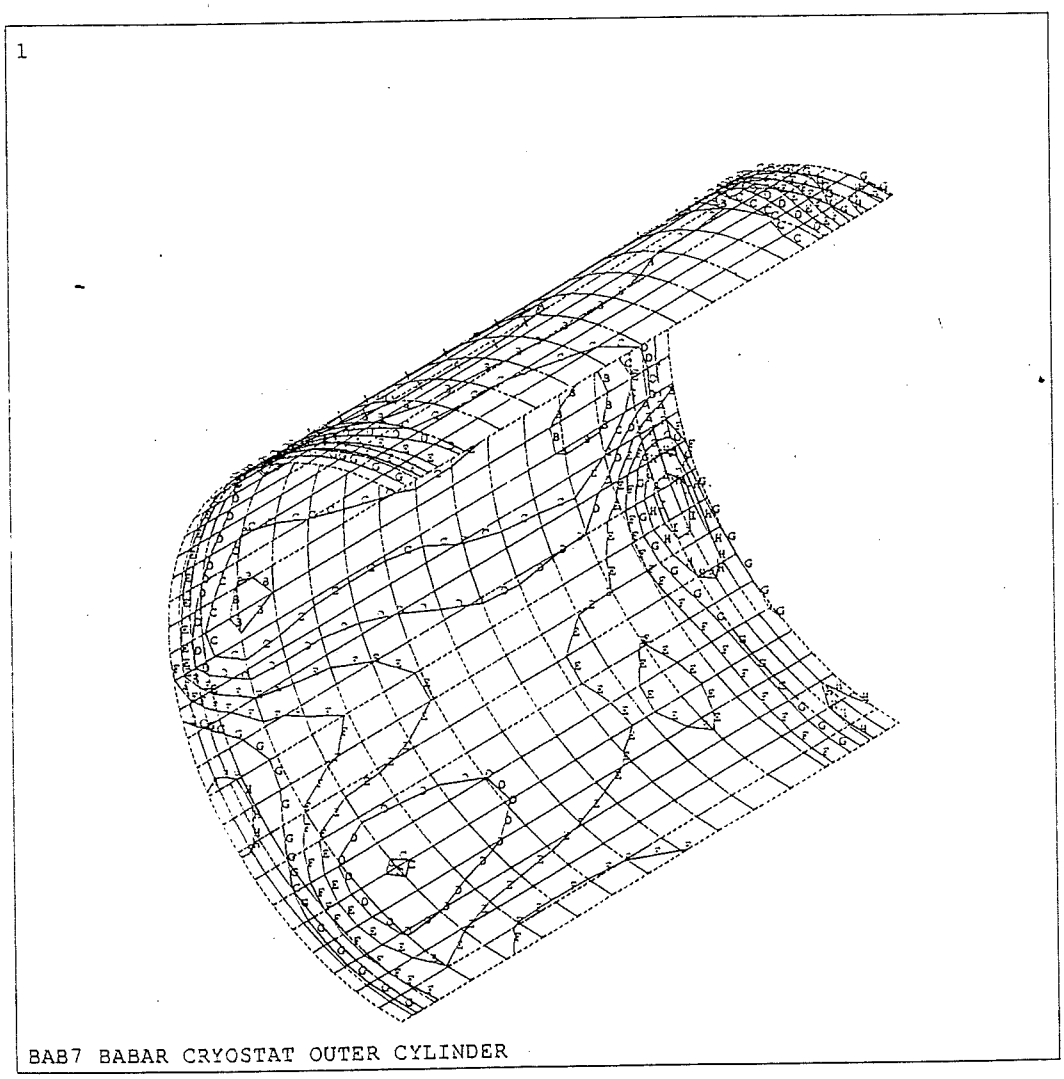
ANSYS 4.4A
SEP 19 1996
14:43:57
PLOT NO. 5
POST1 STRESS
STEP=1
ITER=2
SY (AVG) [Pa]
TOP
CSYS=11
DMX =0.571E-03
SMN =-0.140E+08
SMNB=-0.194E+08
SMX =0.120E+08
SMXB=0.184E+08

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =-0.125E+08
B =-0.965E+07
C =-0.676E+07
D =-0.387E+07
E =-983965
F =0.191E+07
G =0.479E+07
H =0.768E+07
I =0.106E+08



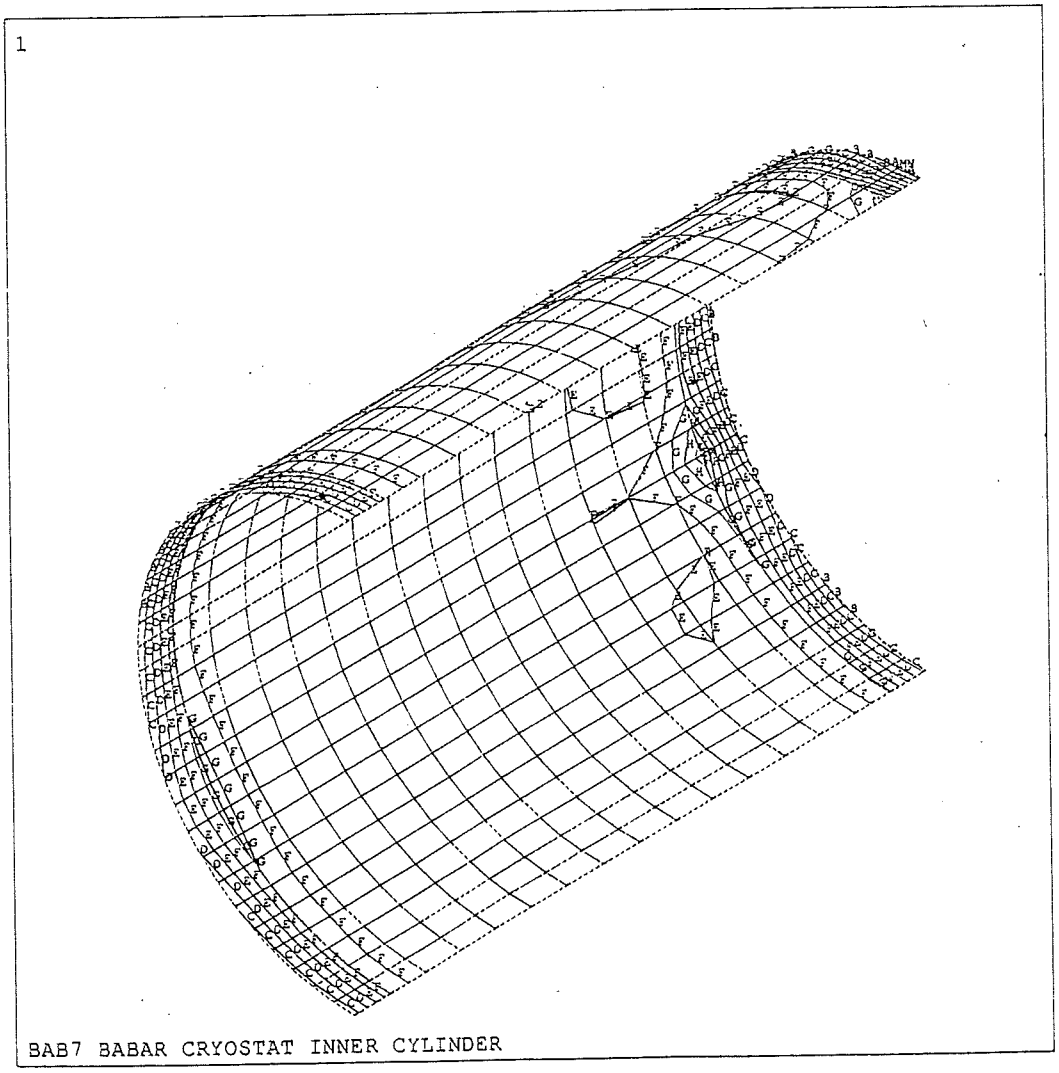
ANSYS 4.4A
SEP 19 1996
14:44:04
PLOT NO. 6
POST1 STRESS
STEP=1
ITER=2
SZ (AVG) [Pa]
TOP
CSYS=11
DMX =0.571E-03
SMN =-0.121E+08
SMNB=-0.179E+08
SMX =0.315E+08
SMXB=0.368E+08

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =-0.969E+07
B =-0.484E+07
C =-385.779
D =0.484E+07
E =0.968E+07
F =0.145E+08
G =0.194E+08
H =0.242E+08
I =0.291E+08



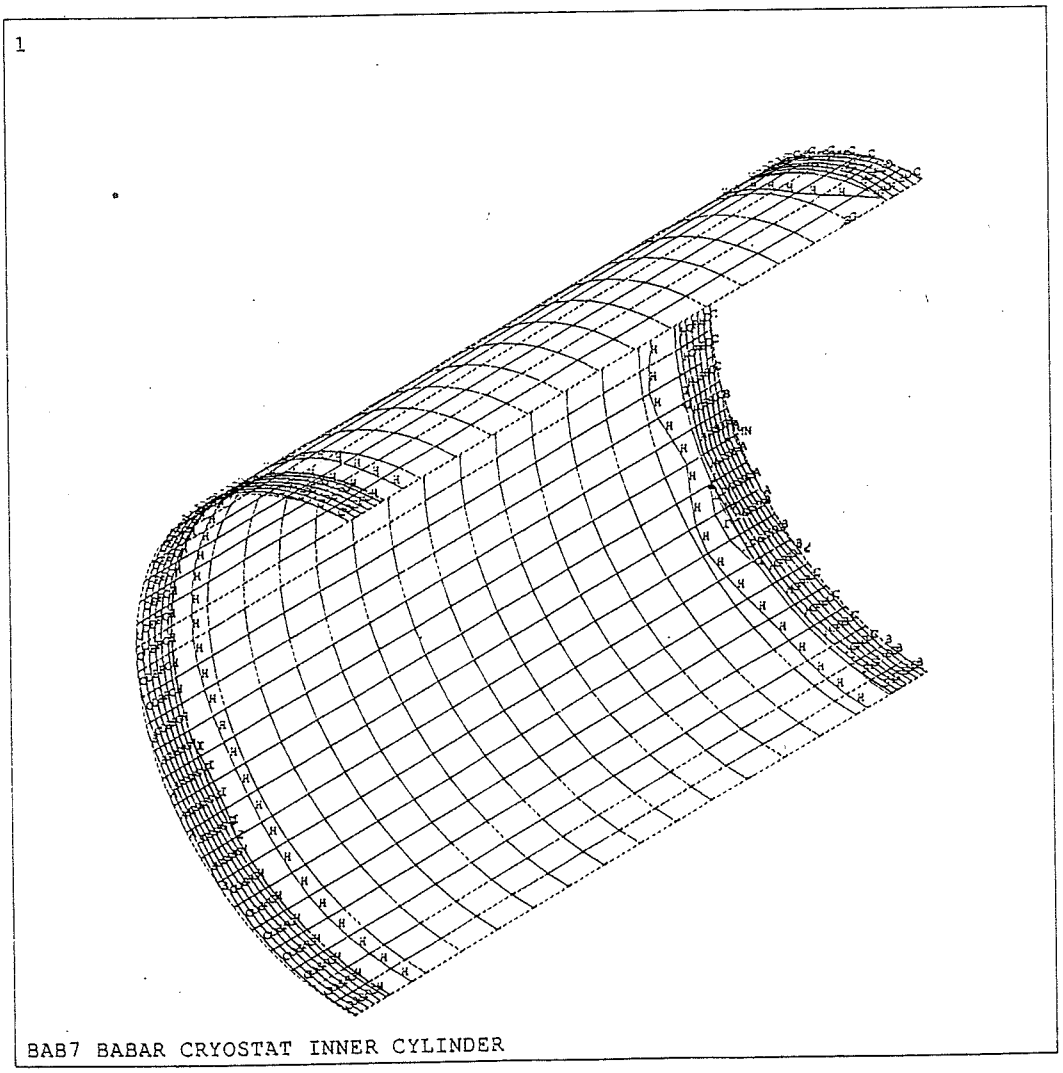
ANSYS 4.4A
SEP 19 1996
14:44:19
PLOT NO. 8
POST1 STRESS
STEP=1
ITER=2
UX [m]
CSYS=11
DMX =0.571E-03
SMN =-0.274E-03
SMX =0.781E-04

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =-0.255E-03
B =-0.216E-03
C =-0.176E-03
D =-0.137E-03
E =-0.981E-04
F =-0.590E-04
G =-0.198E-04
H =0.194E-04
I =0.585E-04



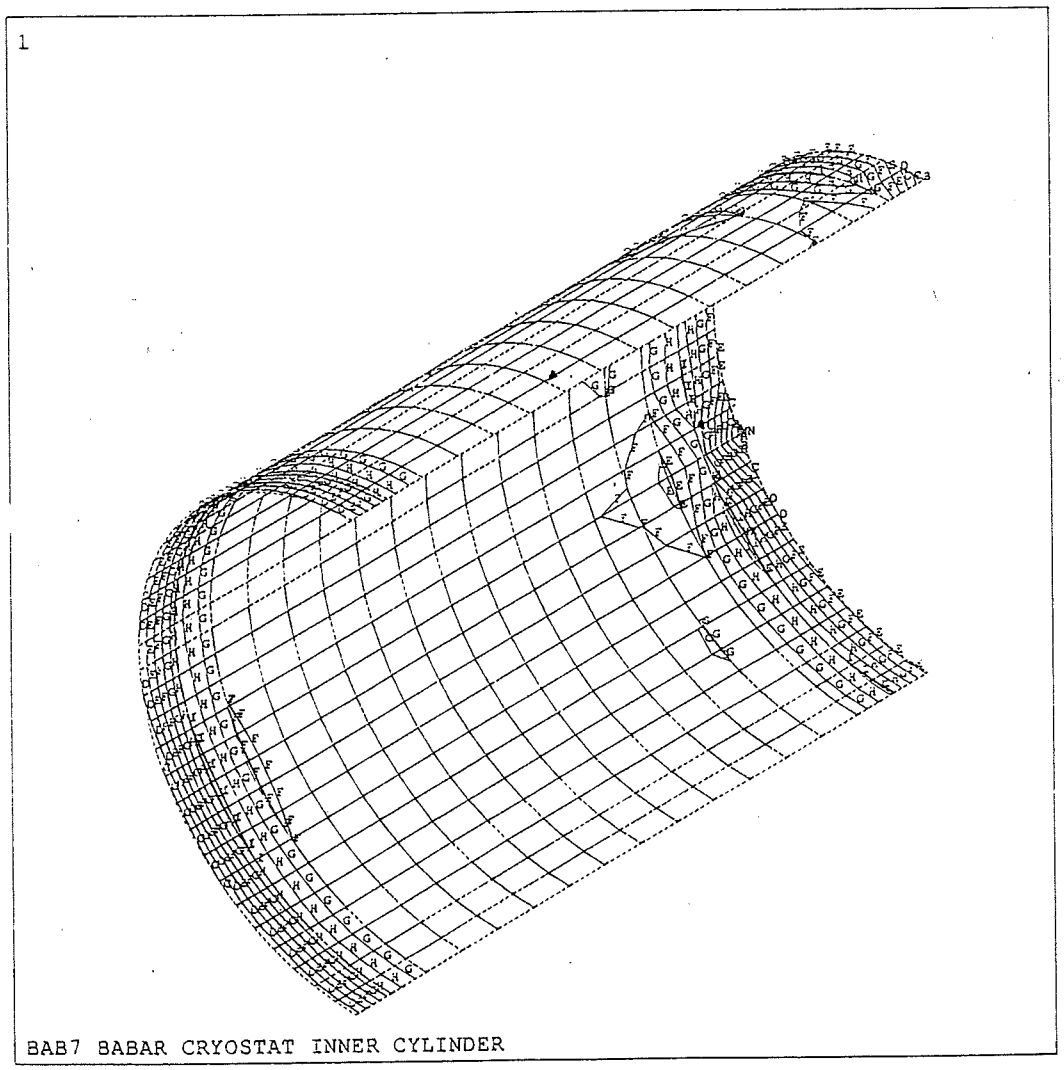
ANSYS 4.4A
SEP 19 1996
14:45:17
PLOT NO. 12
POST1 STRESS
STEP=1
ITER=2
SIGE (AVG) [Pa]
BOTTOM
DMX =0.571E-03
SMN =0.199E+07
SMNB=432551
SMX =0.267E+08
SMXB=0.287E+08

XV =1
YV =1
ZV =1
DIST=2.469
XF =-0.7125
ZF =1.935
PRECISE HIDDEN
A =0.336E+07
B =0.611E+07
C =0.885E+07
D =0.116E+08
E =0.143E+08
F =0.171E+08
G =0.198E+08
H =0.226E+08
I =0.253E+08



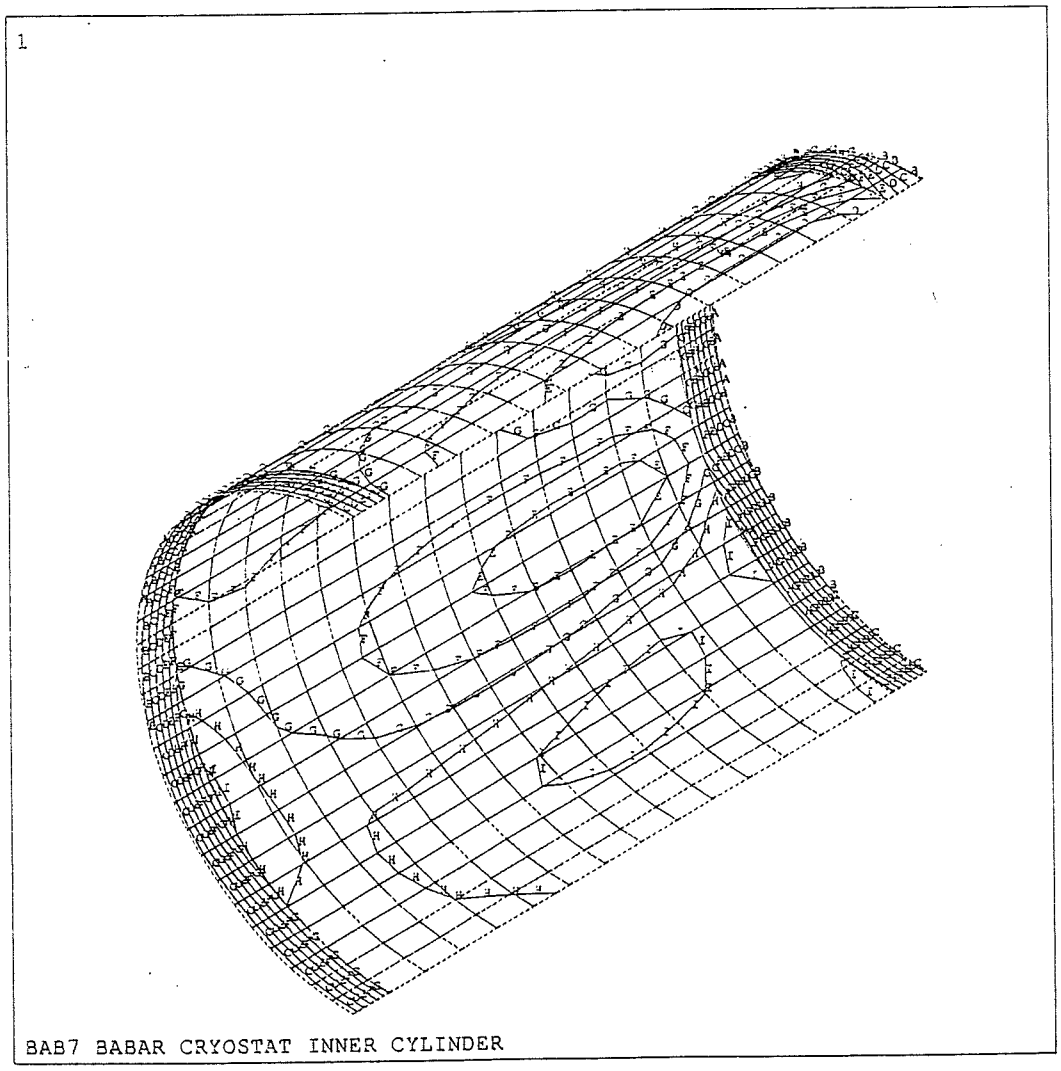
ANSYS 4.4A
SEP 19 1996
14:45:37
PLOT NO. 13
POST1 STRESS
STEP=1
ITER=2
SY (AVG) [Pa]
TOP
CSYS=11
DMX =0.571E-03
SMN =-0.122E+08
SMNB=-0.142E+08
SMX =0.215E+08
SMXB=0.229E+08

XV =1
YV =1
ZV =1
DIST=2.469
XF =-0.7125
ZF =1.935
PRECISE HIDDEN
A =-0.103E+08
B =-0.655E+07
C =-0.281E+07
D =933381
E =0.468E+07
F =0.842E+07
G =0.122E+08
H =0.159E+08
I =0.197E+08



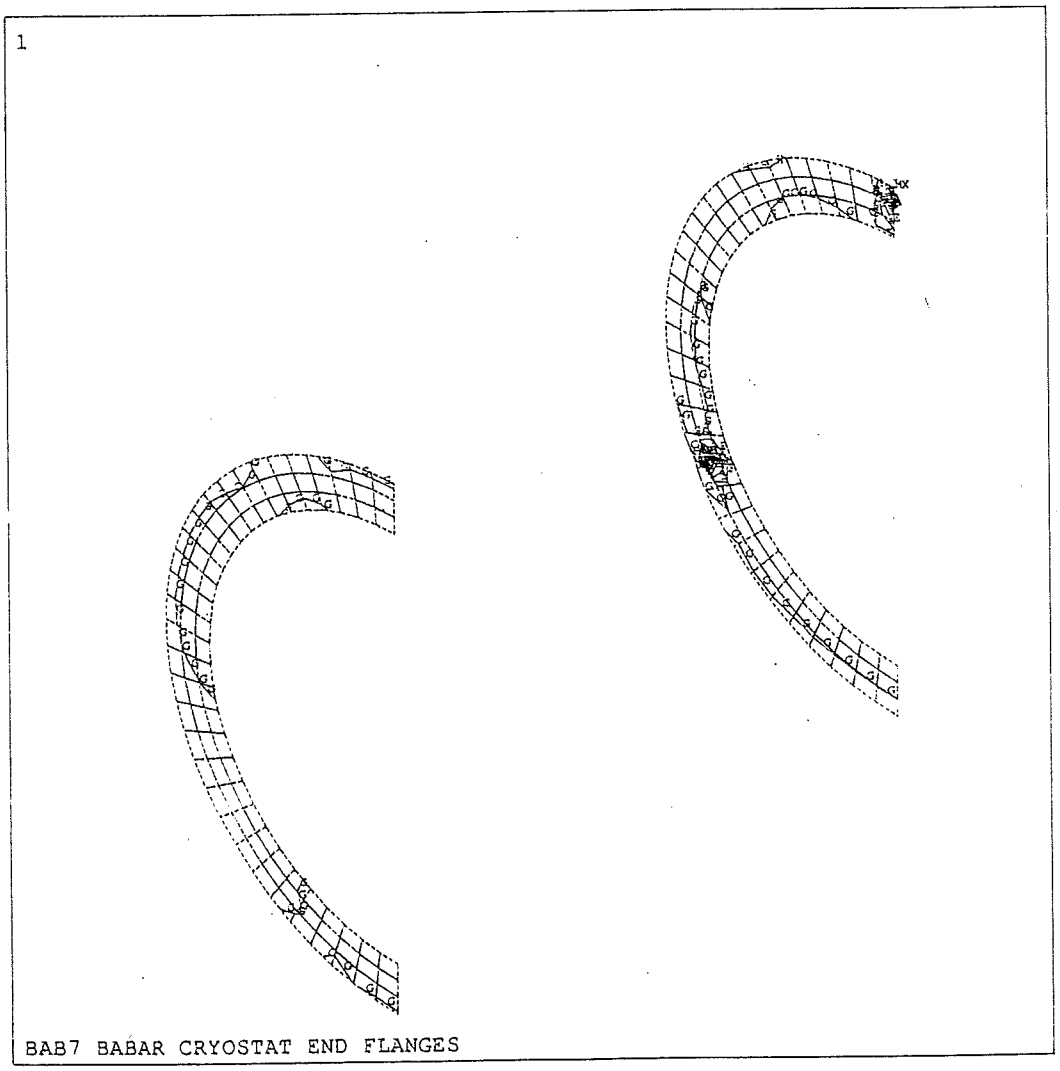
ANSYS 4.4A
SEP 19 1996
14:45:46
PLOT NO. 14
POST1 STRESS
STEP=1
ITER=2
SZ (AVG) [Pa]
TOP
CSYS=11
DMX =0.571E-03
SMN =-0.197E+08
SMNB=-0.217E+08
SMX =0.728E+07
SMXB=0.857E+07

XV =1
YV =1
ZV =1
DIST=2.469
XF =-0.7125
ZF =1.935
PRECISE HIDDEN
A =-0.182E+08
B =-0.152E+08
C =-0.122E+08
D =-0.919E+07
E =-0.620E+07
F =-0.320E+07
G =-208344
H =0.279E+07
I =0.578E+07



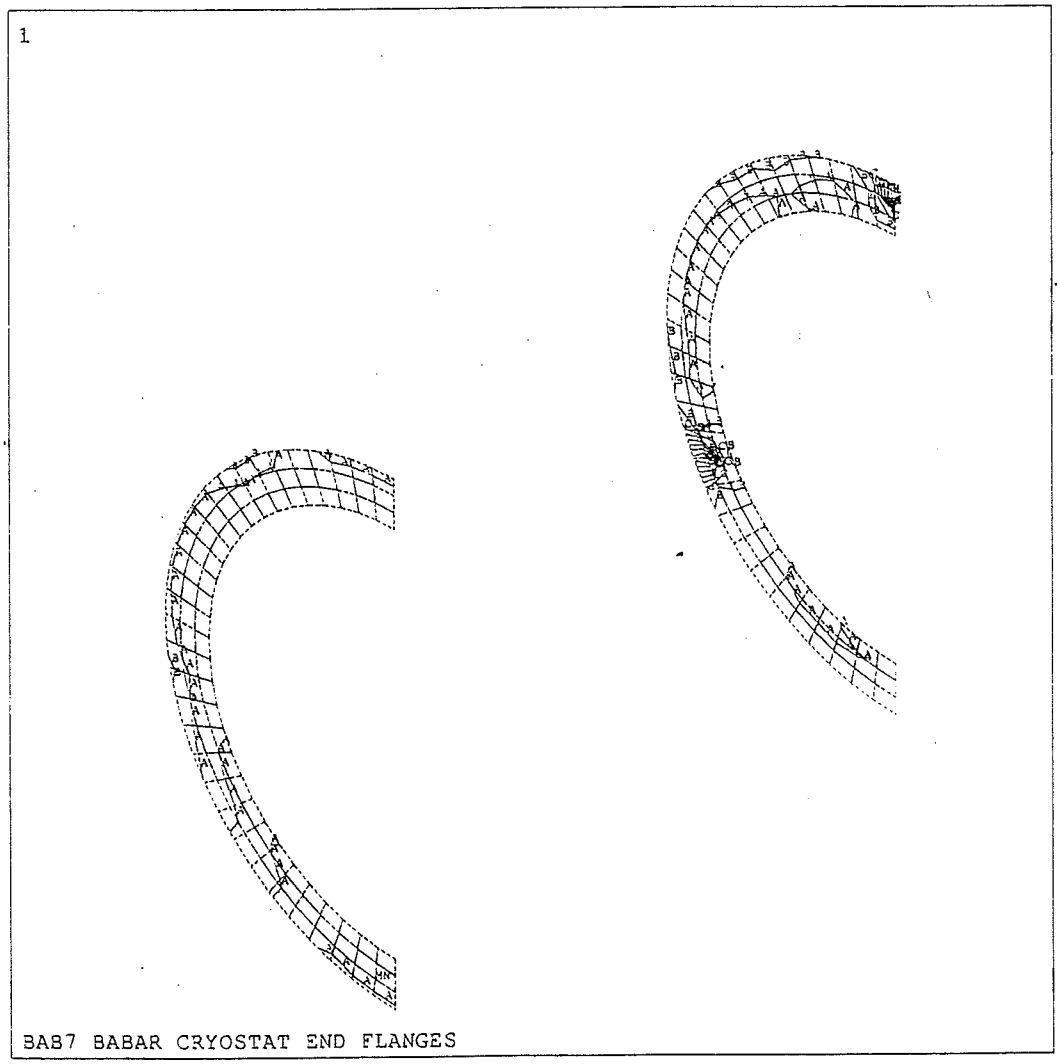
ANSYS 4.4A
SEP 19 1996
14:46:03
PLOT NO. 16
POST1 STRESS
STEP=1
ITER=2
UX [m]
CSYS=11
DMX =0.571E-03
SMN =-0.116E-03
SMX =0.468E-03

XV =1
YV =1
ZV =1
DIST=2.469
XF =-0.7125
ZF =1.935
PRECISE HIDDEN
A =-0.836E-04
B =-0.187E-04
C =0.463E-04
D =0.111E-03
E =0.176E-03
F =0.241E-03
G =0.306E-03
H =0.371E-03
I =0.436E-03



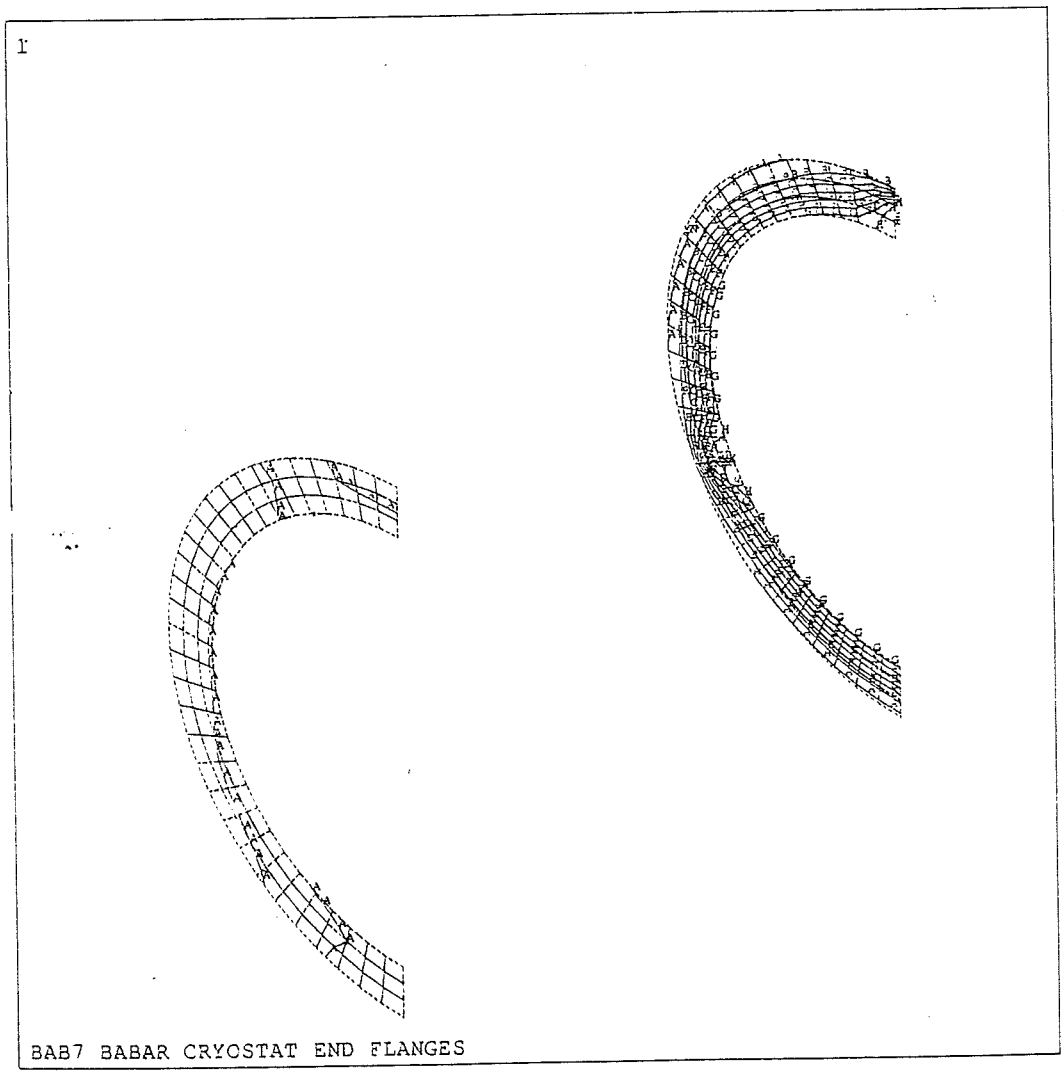
ANSYS 4.4A
SEP 19 1996
14:46:45
PLOT NO. 22
POST1 STRESS
STEP=1
ITER=2
SY (AVG) [Pa]
TOP
CSYS=11
DMX =0.571E-03
SMN =-0.655E+08
SMNB=-0.745E+08
SMX =0.227E+08
SMXB=0.331E+08

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =-0.606E+08
B =-0.508E+08
C =-0.410E+08
D =-0.312E+08
E =-0.214E+08
F =-0.116E+08
G =-0.178E+07
H =0.802E+07
I =0.178E+08



ANSYS 4.4A
SEP 19 1996
14:46:24
PLOT NO. 18
POST1 STRESS
STEP=1
ITER=2
SIGE (AVG) [Pa]
TOP
DMX =0.571E-03
SMN =491086
SMX =0.726E+08
SMXB=0.816E+08

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =0.450E+07
B =0.125E+08
C =0.205E+08
D =0.285E+08
E =0.365E+08
F =0.446E+08
G =0.526E+08
H =0.606E+08
I =0.686E+08



ANSYS 4.4A
SEP 19 1996
14:46:51
PLOT NO. 24
POST1 STRESS
STEP=1
ITER=2
UZ [m]
CSYS=11
DMX =0.571E-03
SMN =-0.157E-04
SMX =0.412E-03

XV =1
YV =1
ZV =1
DIST=2.842
XF =-0.87875
ZF =1.935
PRECISE HIDDEN
A =0.803E-05
B =0.556E-04
C =0.103E-03
D =0.151E-03
E =0.198E-03
F =0.246E-03
G =0.293E-03
H =0.341E-03
I =0.388E-03