1.0 OBJECTIVE

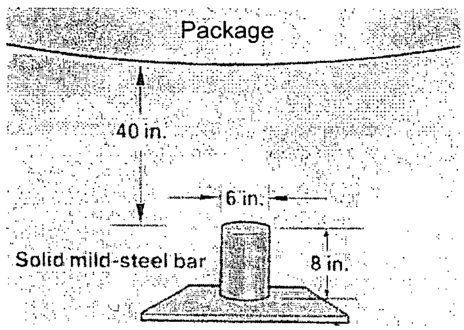
Evaluation of the 3-60B Cask (Reference 1) under:

- Regulatory puncture drop-test
- Hypothetical drop test when the trunnions are orientated in the vertical plane.

2.0 INTRODUCTION

In order to get the 3-60B Cask certified as a Type-B package, it must demonstrate the requirements of the 10 CFR Part 71 (Reference 2) code. One of the requirements listed in the code is for the cask to meet a puncture drop test of § 71.73(c)(3), which states:

"A free drop test of the specimen through a distance of 1 m (40 in) in a position for which maximum damage is expected, onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 15 cm (6 in) in diameter, with the top horizontal and its edge rounded to a radius of not more than 6 mm (0.25 in) and of a length as to cause maximum damage to the package, but not less than 20 cm (8 in) long. The long axis of the bar must be vertical."



This test is required to be conducted after the hypothetical drop tests.

In order to assess the package performance an analytical evaluation is accepted means. This document presents the analyses performed for the 3-60B Cask to meet the requirement of the puncture test.

Two scenarios are identified that could cause the maximum damage to a particular component of the cask. In one, the cask is assumed to be dropped on the puncture bar in a horizontal orientation such that the puncture bar impacts the sidewall of the cask. In this case the outer shell is evaluated against the puncture bar piercing through it. In the other, the cask is assumed to be dropped in a vertical orientation such that its lid impacts the puncture bar. In this case the cask lid is evaluated. The closure bolts are separately evaluated for this condition using NUREG-6007 methodology in the SAR.

For the puncture drop on the sidewall a nonlinear inelastic analysis of the cask wall has been performed using ANSYS (Reference 3) finite element model to show that the entire amount of the potential energy may be converted into mechanical work done, without exceeding the allowable stresses in the cask outer shell.

For the evaluation of the puncture drop on the cask lid, analysis is performed using the linear elastic finite element model that has been used in other evaluations, e.g. NCT conditions (Reference 4). The effect of cold and hot conditions is included in the analyses.

The results of the analyses show that the 3-60B Cask can withstand the drop on the puncture bar, without rupture. Therefore, the requirements of § 71.73(c)(3) are satisfied.

The analyses performed here are also utilized to evaluate the 3-60B Cask under the hypothetical drop tests scenario in which the trunnions are located in the vertical plane. Under such drop scenarios the impact limiters may deform enough so that the trunnions could impact the rigid plane before the cask comes to rest. It has been shown that under all the drop orientations, except the slapdown, the impact limiters provide enough protection that the trunnions will not impact the rigid target plane. Under the slapdown conditions the impact limiters absorb enough energy such that the remaining energy can be safely absorbed by the cask, without damage to the outer shell. Hence the package will meet the requirements of § 71.73(c)(3) for the hypothetical drop test in this orientation.

3.0 REFERENCES

1. Energy*Solutions* Drawing No. C-002-165024-001, Rev.0, 3-60B Cask General Arrangement and Details.

2. Code of Federal Regulations, Title 10, Part 71, Packaging and Transportation of Radioactive Material, January 2003.

3. ANSYS, Rev. 11.0, Computer Software, ANSYS Inc., Canonsburg, PA, 2007.

4. Energy*Solutions* Document No. ST-501, Rev.1, Structural Analyses of the 3-60B Cask under Normal Conditions of Transport.

5. ASME Boiler & Pressure Vessel Code, Section II, Part D, Materials, The American Society of Mechanical Engineers, New York, NY, 2005.

6. NUREG 0481/SAND77-1872, An Assessment of Stress-Strain Data Suitable for Finite Element Elastic-Plastic Analysis of Shipping Containers, Sandia National Laboratories, 1978.

7. U.S. NRC Regulatory Guide 7.6, Revision 1, Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels, 1978.

8. Energy*Solutions* Proprietary Document ST-557, Drop Analyses of the 3-60B Cask Package Using LS-DYNA Program.

4.0 MATERIAL PROPERTIES

Material	Temp. (°F)	Strength (ksi)			Young's Modulus (10^6 psi)	Coefficient of Thermal Expansion (10^{-6} in/in)
		Yield (S_y)	Ultimate (S_u)	Membrane Allowable (S_m)		
		(1)	(1)	(1)	(1)	(1)
ASTM A240 Type 304L	-20	25.0	70.0	16.7	28.8	-
	70	25.0	70.0	16.7	28.3	8.5
	100	25.0	70.0	16.7	-	8.6
	200	21.4	66.1	16.7	27.5	8.9
	300	19.2	61.2	16.7	27.0	9.2
	400	17.5	58.7	15.8	26.4	9.5
	500	16.4	57.5	14.7	25.9	9.7
		(1)	(1)	(1)	(1)	(1)
ASTM A240 Gr. 45 & ASTM A182 Gr. F45	-20	45.0	87.0	24.9	28.8	-
	70	45.0	87.0	24.9	28.3	8.5
	100	45.0	87.0	24.9	-	8.6
	200	37.5	86.4	24.7	27.5	8.9
	300	33.0	81.6	23.3	27.0	9.2
	400	29.9	78.5	22.4	26.4	9.5
	500	27.8	76.4	21.8	25.9	9.7
		(1)	(1)	(1)	(1)	(1)
ASTM A354 Gr. BD (Lid Bolts)	-20	130	150	30	29.7	-
	70	130	150	30	29.2	6.4
	100	130	150	30	-	6.5
	200	119.1	150	30	28.6	6.7
	300	115	150	30	28.1	6.9
	400	111	150	30	27.7	7.1
	500	105.9	150	30	27.1	7.3
		(2)			(2)	(2)
ASTM B29 Lead	-20	-	-	-	2.43	15.65
	70	5	-	-	2.27	16.06
	100	-	-	-	2.21	16.22
	200	-	-	-	2.01	16.70
	300	-	-	-	1.85	17.33
	400	-	-	-	1.70	18.16
	500	-	-	-	1.52	19.12

Notes:

(1) From ASME B&PV Code 2004, Section II, Part D (Reference 5).

(2) From NUREG/CR 0481 (Reference 6)

5.0 ALLOWABLE STRESSES

Material →		ASTM A240 Type 304L	ASTM A182 Gr.F45 & A240 Gr. 45	ASTM A354 Gr. BD
Yield Stress, S_y (psi)		25,000(1)	45,000(1)	130,000(1)
Ultimate Stress, S_u (psi)		70,000(1)	87,000(1)	150,000(1)
Design Stress Intensity, S_m (psi)		16,700(1)	24,900(1)	30,000(1)
Normal Conditions	Membrane Stress	16,700(2)	24,900(2)	60,000(2)
	Mem. + Bending Stress	25,050(2)	37,350(2)	90,000(2)
	Peak Stress	50,100(3)	74,700(3)	150,000(3)
Hypothetical Accident Conditions	Membrane Stress	40,080(4)	59,760(4)	105,000(4)
	Mem. + Bending Stress	60,120(4)	87,000(4)	150,000(4)
	Peak Stress	140,000(5)	174,000(5)	300,000(5)

Notes:

(1) From ASME B&PV Code 2004, Section II, Part D (Reference 5).

(2) Established from Regulatory Guide 7.6 (Reference 7).

(3) Established from Regulatory Guide 7.6, Regulatory Position 4, and ASME, Section III, Division 3, WB-3200 criteria. The limit on this stress component is $3S_m$.

(4) Regulatory Guide 7.6 (Reference 7) does not provide any criteria. ASME B&PV Code, Section III, Appendix F has been used to establish these criteria.

(5) Regulatory Guide 7.6, Regulatory Position 7 and ASME Section III, Division 3, WB-3221.9 criteria of limiting these stresses to $2S_a$ @ 10 cycles results in higher than $2S_u$ allowable values. The limits for peak stresses are conservatively set to be $2S_u$.

6.0 MODEL DESCRIPTION

The structural analyses of the 3-60B Cask under puncture drop conditions have been performed using finite element modeling techniques. ANSYS finite element analysis code

(Reference 3) has been employed to perform the analyses. Two different models have been employed to address two puncture drop scenarios.

6.1 Scenario 1: Puncture Drop on the Sidewall

The puncture drop on the sidewall causes high local stresses at the point of contact. The magnitude of these stresses attenuates quickly with distance. Thus for the evaluation of the stresses in the cask under this loading a finite element model representing the sidewall in the vicinity of the impact has been employed. Since the cylindrical cask-to-the cylindrical pin impact provides two planes of symmetry, the model uses two vertical symmetry planes. In the horizontal plane there is no plane of symmetry. However, since the stresses resulting from the impact are highly local, based on St. Venant's principle, approximate boundary conditions on the horizontal plane will have little effects on the stresses at the point of impact. Symmetry boundary conditions on this plane, in fact will result in a conservative stress prediction. Thus the FEM used in the analysis has three planes of symmetry. This model is shown in Figure 1.

6.2 Scenario 2: Puncture Drop on the Lid

For the puncture drop on the lid, the cyclic symmetry of the cask has been utilized. Since the lid of the cask is attached to the body using 16 bolts, the cask geometry has a cyclic symmetry every 11.25° of the circumference. Therefore, an 11.25° model of the cask is made using 3-dimensional 8-node structural solid elements (ANSYS SOLID185) to represent the major components of the cask, the cask body, the lid, and the bolts. The fire shield does not provide any structural strength to the cask. Therefore, it is not included in the model.

The poured lead in the body of the cask is not bonded to the steel. It is free to slide over the steel surface. Therefore, the interface between the lead and the steel is modeled by a pair of contact (CONTA174) and target (TARGE170) elements. These elements allow the lead to slide over the steel at the same time prevent it from penetrating the steel surface.

Figure 2 shows the finite element model of the cask used for the puncture drop analysis of 3-60B on its lid.

7.0 RESULTS & CONCLUSIONS

7.1 Scenario 1: Puncture Drop on the Sidewall

Analyses using the FEM described in Section 6.1 are performed for obtaining the force-deflection plot. A known amount of load is applied in form of surface pressure at the end of the puncture bar. The deflection of the bar is obtained from the analysis of the FEM. Figure 3 shows the force-deflection plot at the end of the rod. The area under this plot gives the work done versus deflection relation. Using Microsoft Excel spreadsheet program the force-deflection curve is integrated to obtain the work done versus deflection plot shown in Figure 4. Energy versus deflection diagram also created as follows:

Mass of the package = 80,000 lb

Height of the package = 40 in

Assuming that the package travels an additional distance δ before it comes to stop, the total potential energy is:

$$PE(\delta) = 80{,}000\times(40+\delta)$$

This curve is also plotted in Figure 4. The intersection of the potential energy curve and the work done curve represent the energy balance point. Any loading larger than that at the intersection point, applied to the FEM can be used to conservatively calculate the stresses in the structure. A loading much larger than the balance point loading is used to compute the stresses. This loading point is shown in Figure 4. Its selection is based on the fact that it envelopes the puncture drop loading and the cask drop on the trunnion loading covered in Section 7.3 of this document.

Figure 5 shows the maximum stress intensity in the inner and outer shells of the cask under this loading. Figure 6 shows the maximum stress intensity in the lead and Figure 7 shows the stress intensity in the outer shell of the cask under this loading.

From Figures 5 to 7, the maximum stress intensity in the lead is small (6,507 psi) and the maximum stress intensity in the outer shell is 63,084 psi. This stress intensity is compared to the ultimate tensile strength of the shell material, i.e. 70,000 psi. It is, therefore, concluded that the 3-60B Cask can safely withstand the regulatory puncture drop on its sidewall.

7.2 Scenario 2: Puncture Drop on the Lid

The puncture bar has 6" diameter and it is made of mild steel. Conservatively assuming a flow stress of 45,000 psi for the mild steel, the corresponding load is:

$$F = \pi/4\times6^2\times45{,}000 = 1.272\times10^6 \text{ lb}$$

This load is applied over a circle of 3.333 in. The equivalent pressure is therefore,

$$p = 1.272\times10^6/(\pi\times3.333^2) = 36{,}447 \text{ psi}$$

This load is applied as a surface pressure on the model described in Section 6.2. Both cold and hot environments have been analyzed for this loading.

The stresses in the cask under this loading are shown in Figures 8 through 10. From these figures it is observed that the maximum stress intensity occurs in the lid at the point of impact and its value is 41,568 psi. This stress intensity is compared to the ultimate tensile strength of the lid material, i.e. 70,000 psi. It is, therefore, concluded that the 3-60B Cask can safely withstand the regulatory puncture drop on its sidewall.

7.3 Impact on Trunnion during HAC Testing

Analyses of the 3-60B Cask have been performed in Reference 8 for the HAC drop test loading conditions. These analyses were performed using finite element models of the package with its major components. Since the objective of these analyses was to obtain the impact limiter reactions, detailed modeling of the cask was not necessary. However, from these analyses the complete deformation of the package can be obtained. These deformations could be used to establish whether the trunnions of the cask will contact the rigid target surface if the cask were to be dropped in an orientation such that the trunnions were located in the vertical plane as shown in Figure 11.

From the geometry of the package shown in Figure 11, the vertical distance between the lowest point of the impact limiter to the lowest point of the trunnions is 8 in. From the results of the Reference 8 analyses the maximum crush of the impact limiters during various drop scenarios is as follows:

Drop Orientation	Environment	Max. Crush
Side	Cold	6.50
	Hot	8.02
Slapdown-1	Cold	7.44
	Hot	9.04
Slapdown-2	Cold	7.23
	Hot	8.86

It can be seen that for most drop orientations the impact limiter crush is less than the minimum foam thickness available, i.e. 8 in. The largest crush of the impact limiter occurs during the slapdown-1 orientation (7½° form the horizontal) in the hot environment. Figure 12 shows a pictorial depiction of the deformation of the package at the instant of maximum tail impact limiter crush. Figure 13 shows the time-history of this crush. The internal energy time-history of the package is shown in Figure 14.

Figures 13 and 14 are used to establish the amount of energy that has been absorbed by the impact limiters before the tail-end trunnion could impact the rigid surface. The foam of the tail-end impact limiter crushes by 8" at time instant 0.057 second (see Figure 13). Figure 14 shows that at this time instant 12.2×10^6 in-lb energy has been absorbed by the impact limiters. Since the result is for ½ model. The energy absorbed is $2\times12.2\times10^6 = 24.4\times10^6$ in-lb.

The maximum potential energy of the package is obtained from its initial to final (resting) positions. Figure 15 shows these orientations. The distances of the C.G. for the two positions are also marked in this figure. The potential energy of the system is:

$$PE = 80{,}000 \times (360 + 51.418 - 35.025) = 30.1 \times 10^6 \text{ in-lb}$$

Since 24.4×10^6 in-lb energy has already been absorbed in the impact limiters, the rest of the energy, i.e. $(30.1 - 24.4) \times 10^6 = 5.7 \times 10^6$ in-lb must be accounted for between the crush of the trunnion and that of the tail-end impact limiter. Let us conservatively assume that this energy is totally absorbed by the cask body by the trunnion crush. The minimum diameter of the trunnion body is 8". Therefore, during the trunnion crush the load on the cask sidewall will be distributed over 8" circular area. Let us further conservatively assume that the bearing area on the cask is a circle of 6" diameter which is equal to the diameter of the puncture bar. Therefore, the evaluation performed for the puncture bar drop can be conservatively used to envelope the stresses in the package sidewall for direct impact on the trunnion during the HAC drop tests. Figure 4 annotates 5.7×10^6 in-lb location on the energy-deflection plot curve.

In Section 7.2 stresses are evaluated in the cask sidewall for a loading level that envelopes both the puncture drop loading and the cask drop on the trunnion loading. It is shown that the maximum stress intensity of 63,084 psi will result in the cask sidewall under these loading conditions (see Figure 7). This stress intensity is compared to the ultimate tensile strength of the shell material, i.e. 70,000 psi. It is, therefore, concluded that the 3-60B Cask can safely withstand the regulatory HAC drop tests, with its trunnions oriented in the vertical plane, without exceeding the allowable stress value.

8.0 ANSYS PRINTOUT AND DATA FILES

The printout of the pertinent model quantities is included in Appendix 1. The printout of the important data from the program is included in electronic form as Appendix 2.

APPENDICES

Appendix 1 Print-out of the ANSYS model data input

Appendix 2 Electronic data on CDROM

Figures

(15 Pages)

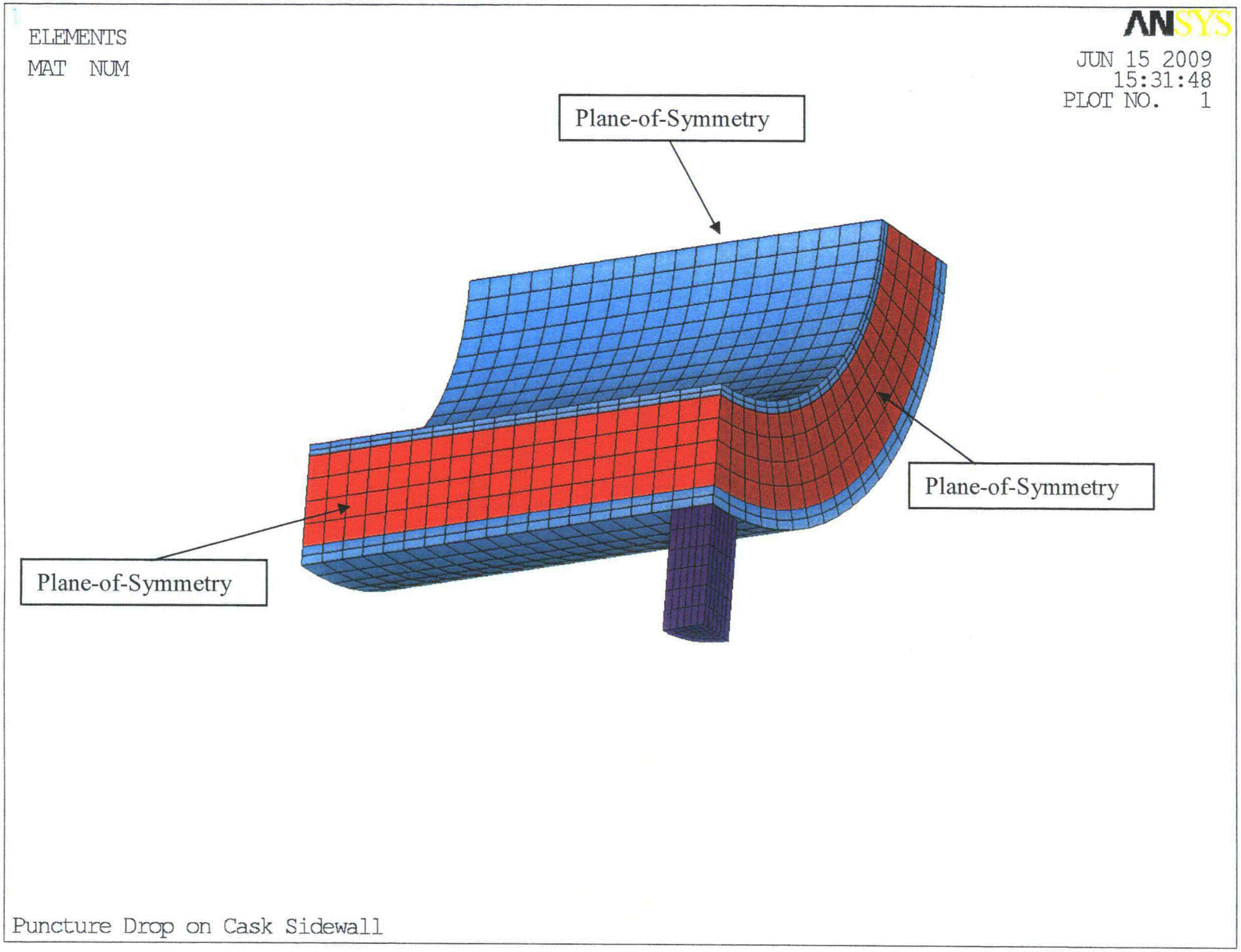


Figure 1

Finite Element Model of the 3-60B Cask for Puncture Drop on the Sidewall Analysis

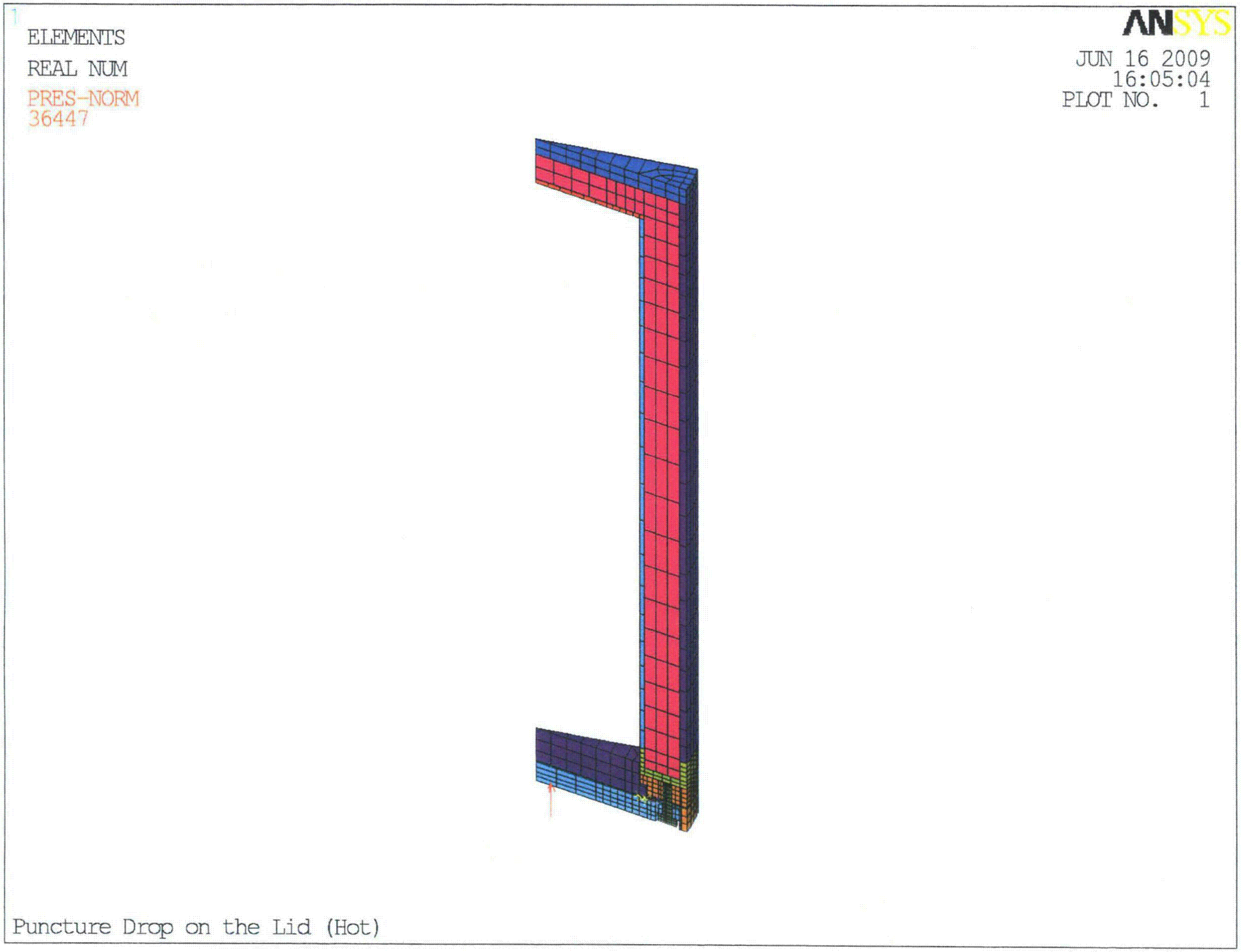


Figure 2

Finite Element Model of the 3-60B Cask for Puncture Drop on the Lid Analysis

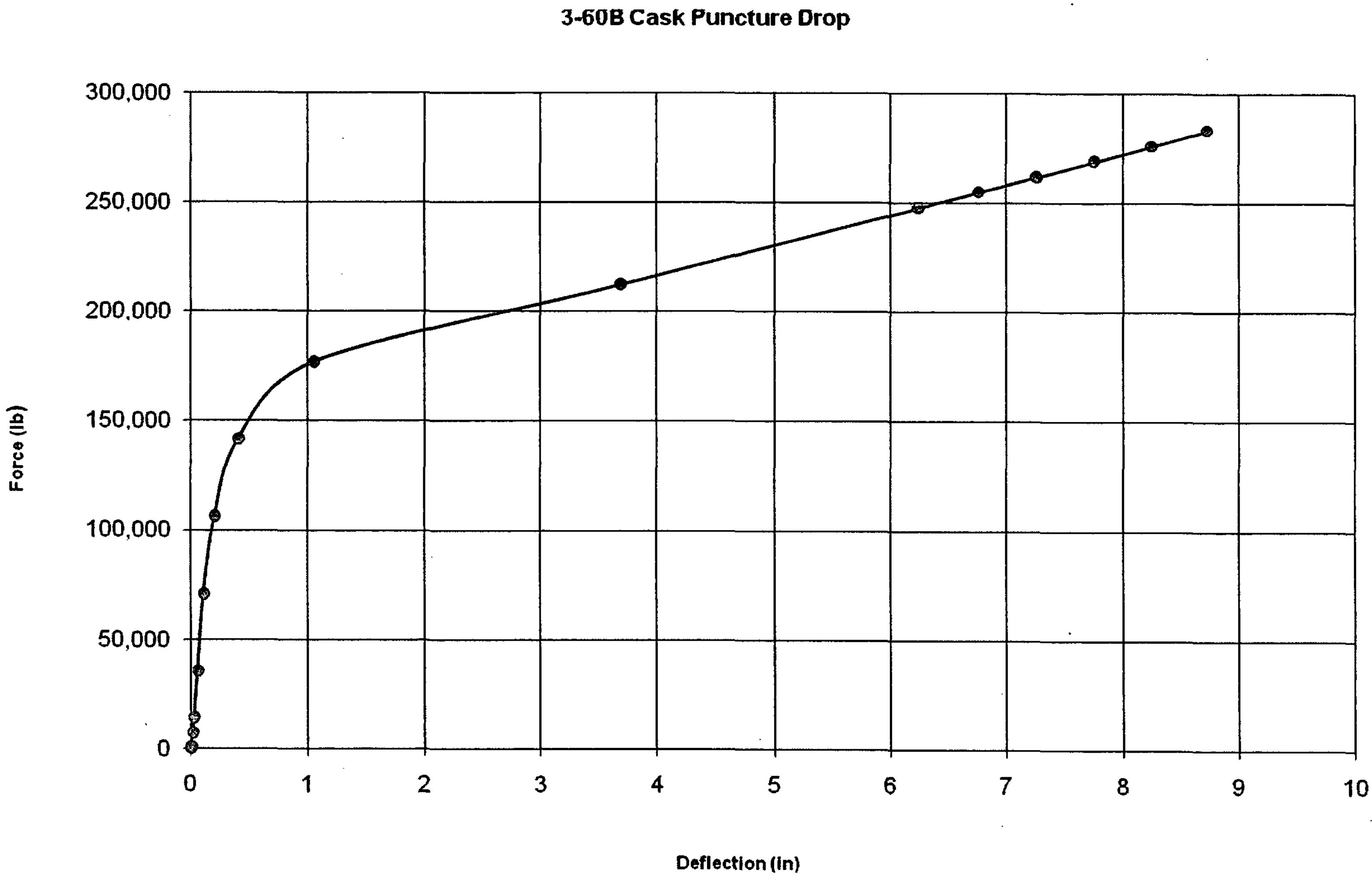


Figure 3
Force-Deflection Plot at the Point of Impact

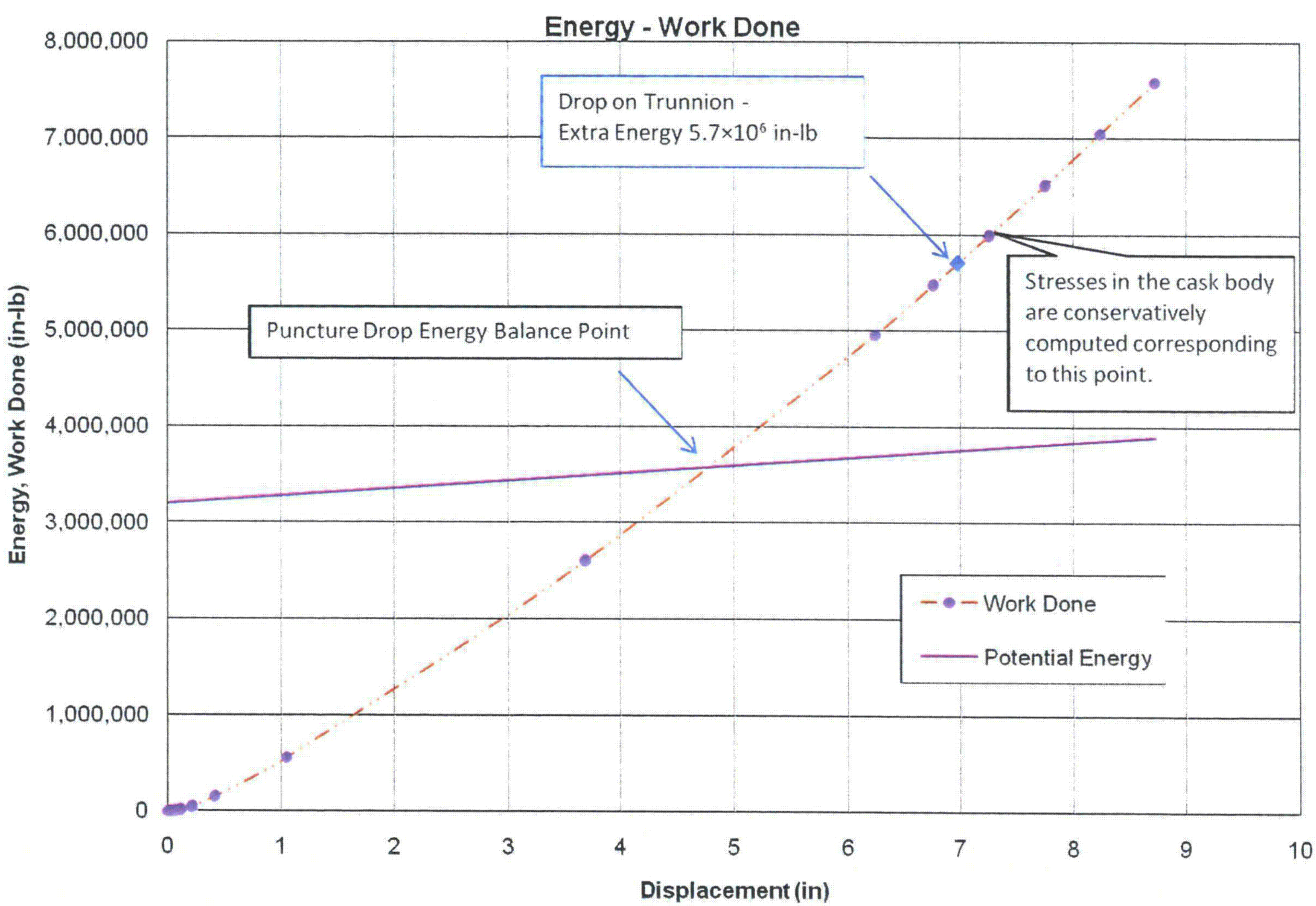


Figure 4
Energy versus Deflection Plot

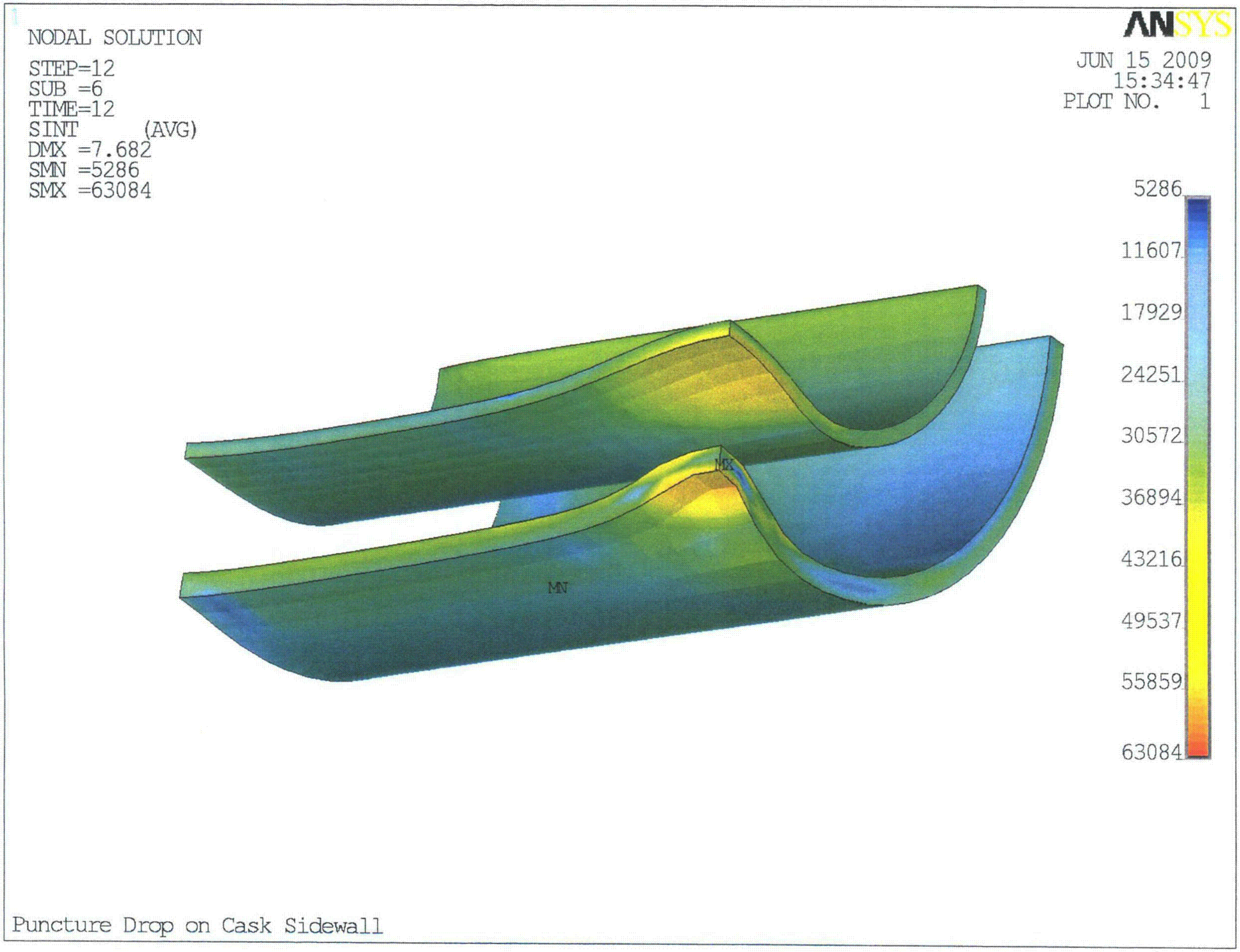


Figure 5

Maximum Stress Intensity in the Inner & Outer Shells of the Cask under Puncture Drop

Title 3-60B Cask Analyses under Puncture Drop & Impact on Trunnions during HAC Testing

Calc. No. ST-505 (Figures) Rev. 1 Sheet 5 of 15

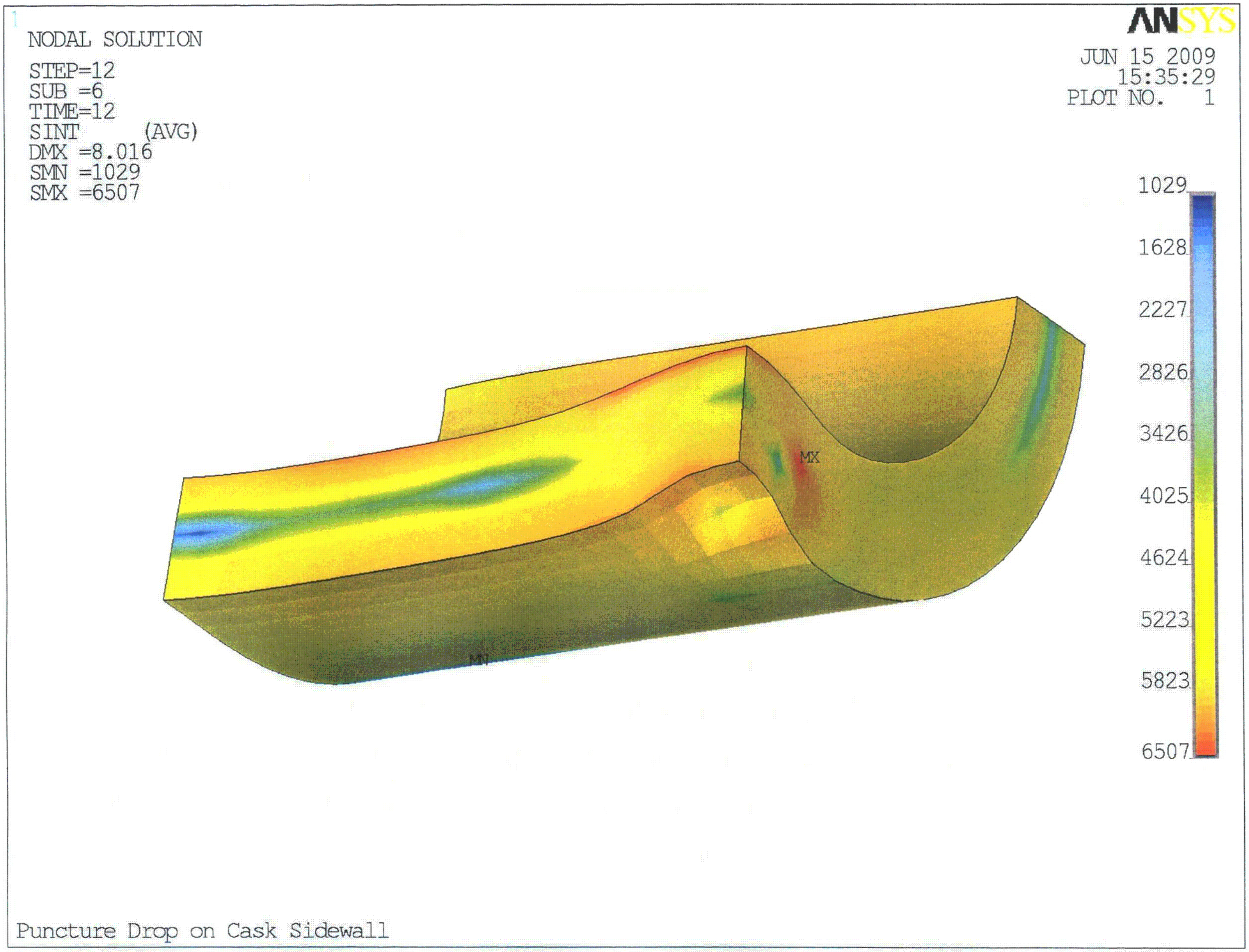


Figure 6

Maximum Stress Intensity in the Lead under Puncture Drop

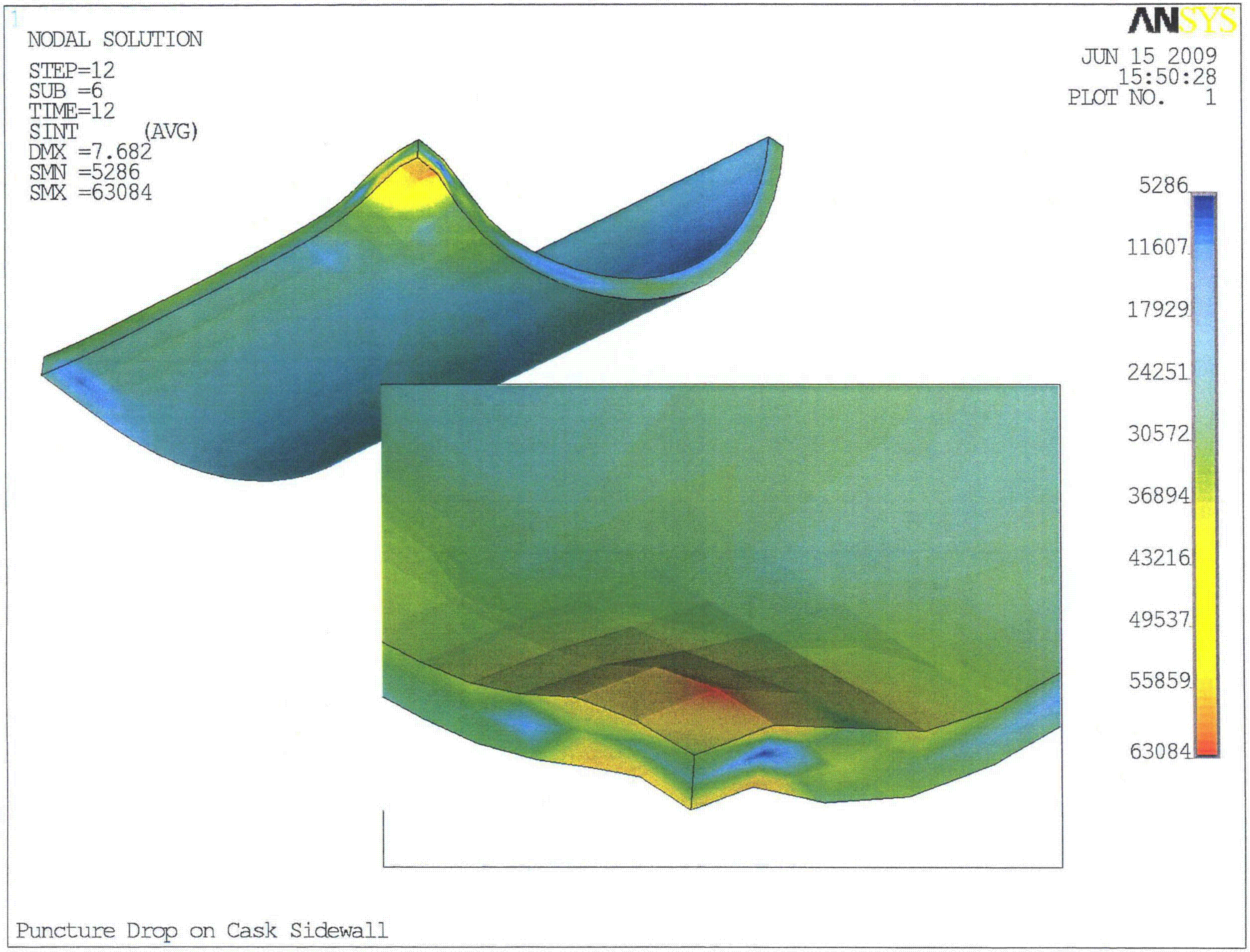


Figure 7

Maximum Stress Intensity in the Outer Shells of the Cask under Puncture Drop

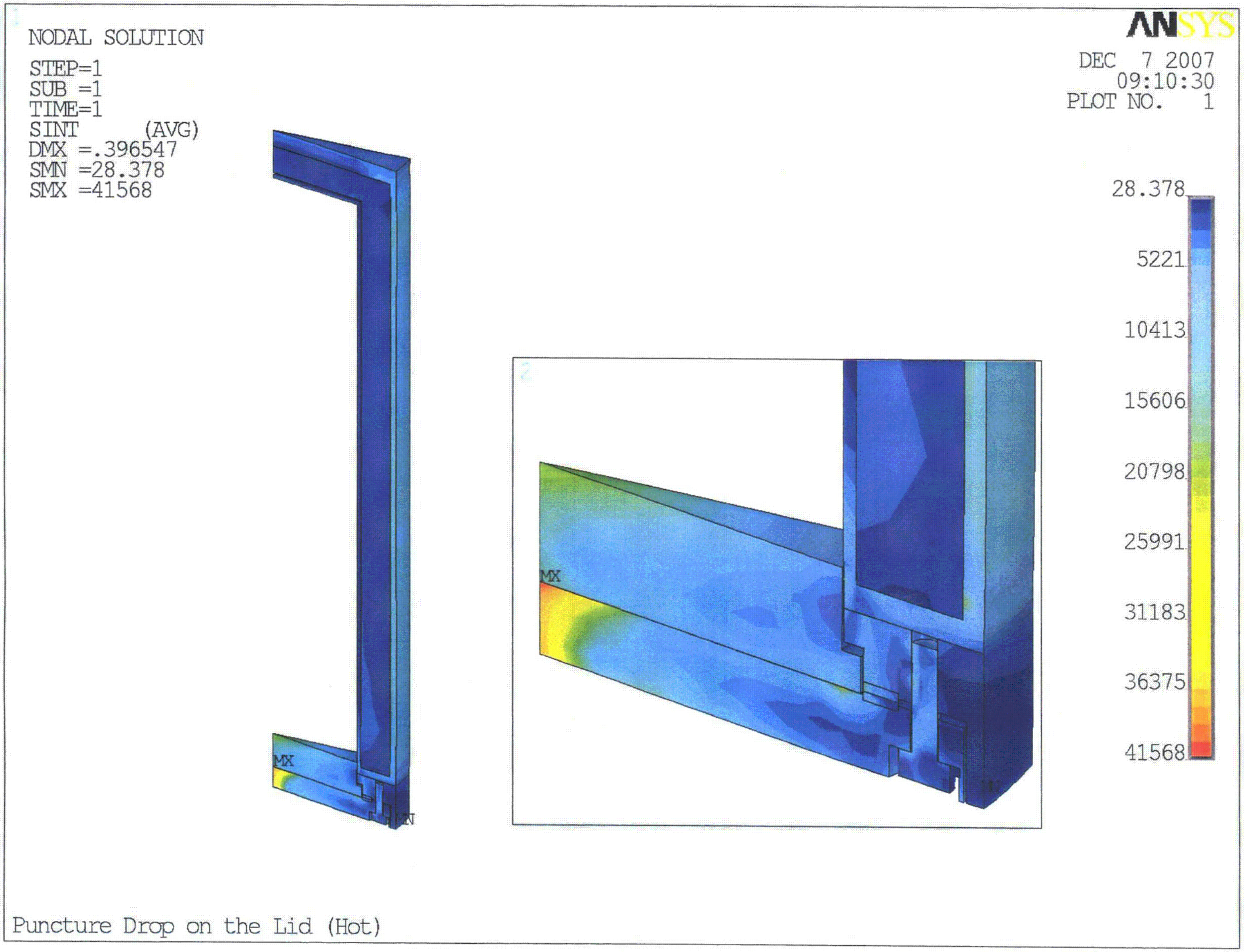


Figure 8
Maximum Stress Intensity in the Cask under Puncture Drop on the Lid

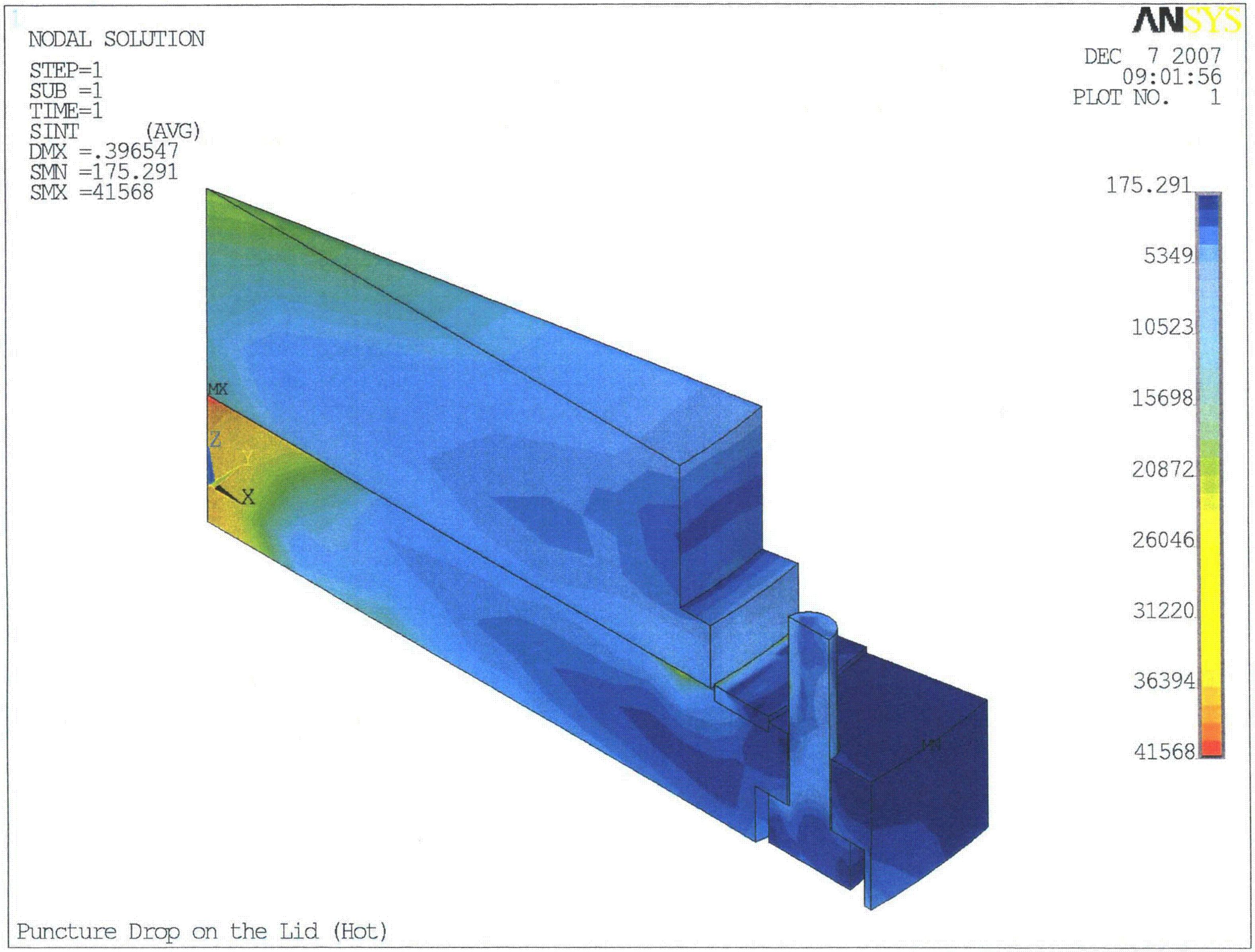


Figure 9
Maximum Stress Intensity in the Lid under Puncture Drop (Hot Conditions)

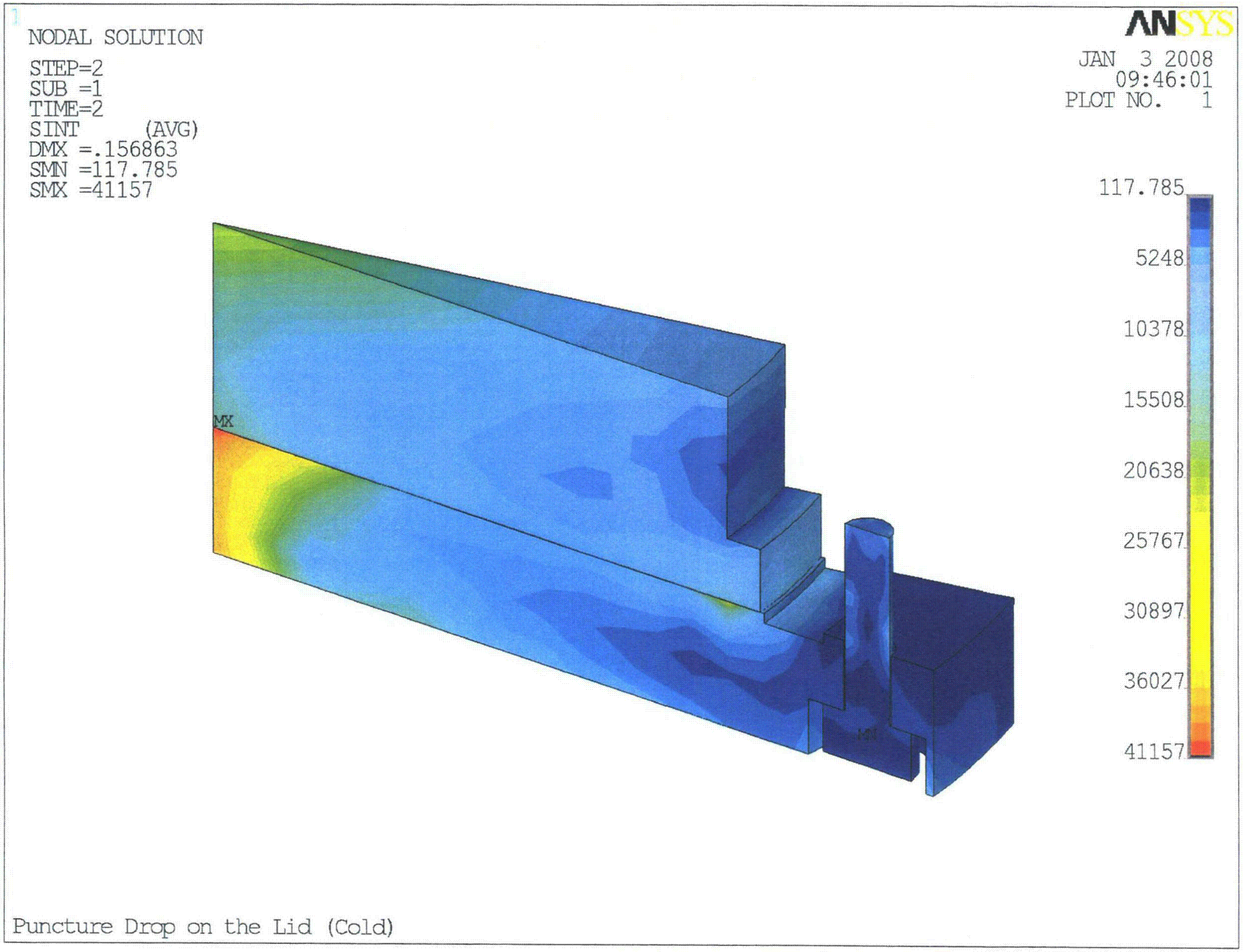


Figure 10
Maximum Stress Intensity in the Lid under Puncture Drop (Cold Conditions)

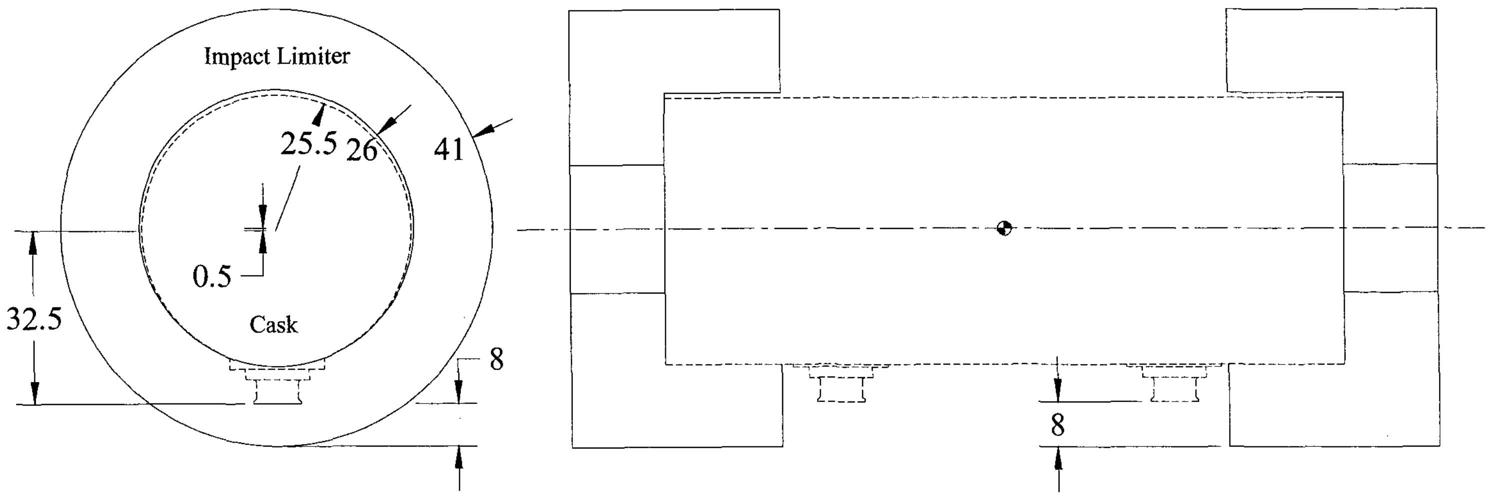


Figure 11
Package Geometry with Trunnions in the Vertical Plane

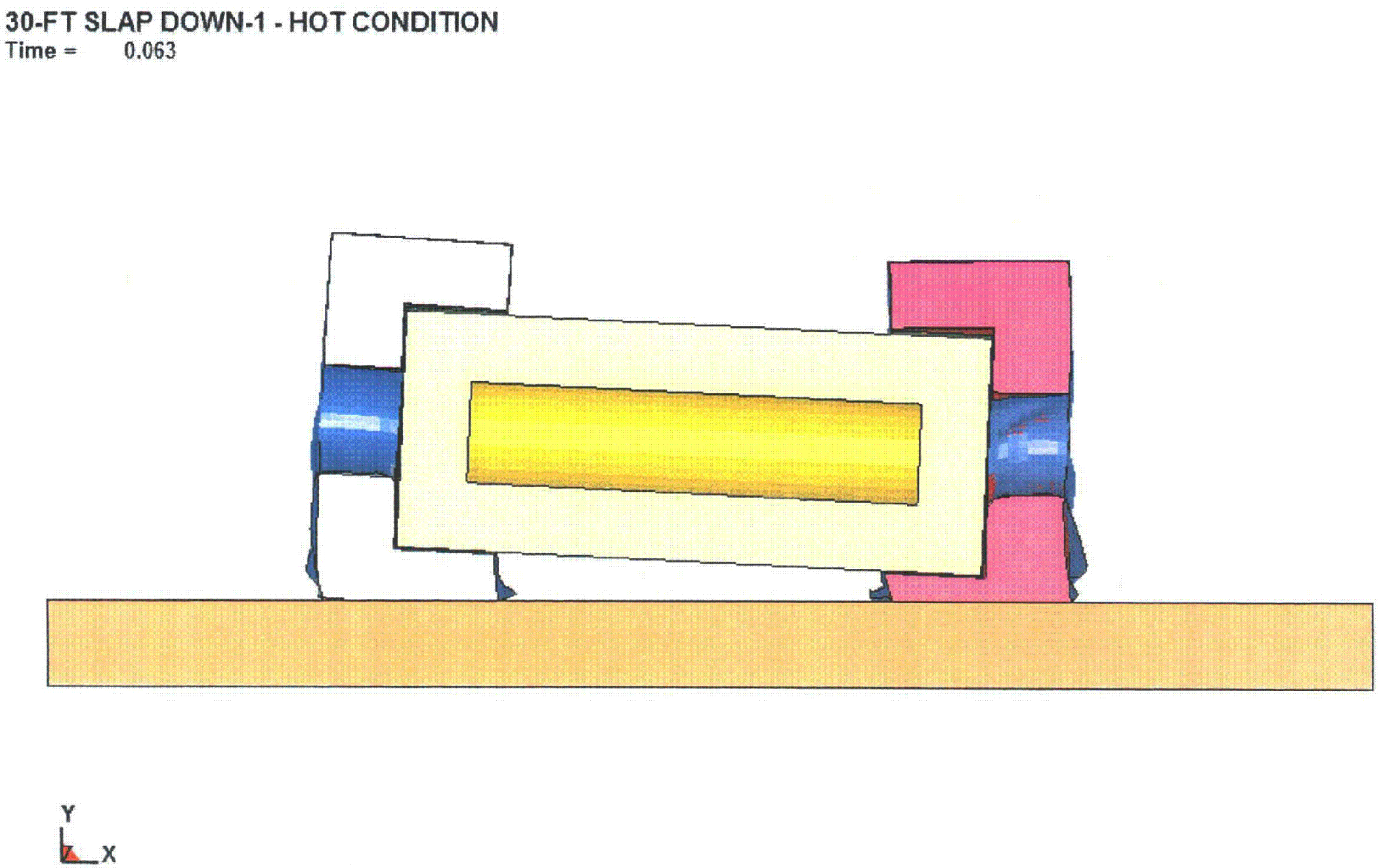


Figure 12
Deformation of the Impact Limiters with 8" Foam Crush at the Tail End
(Reference 8 Analysis)

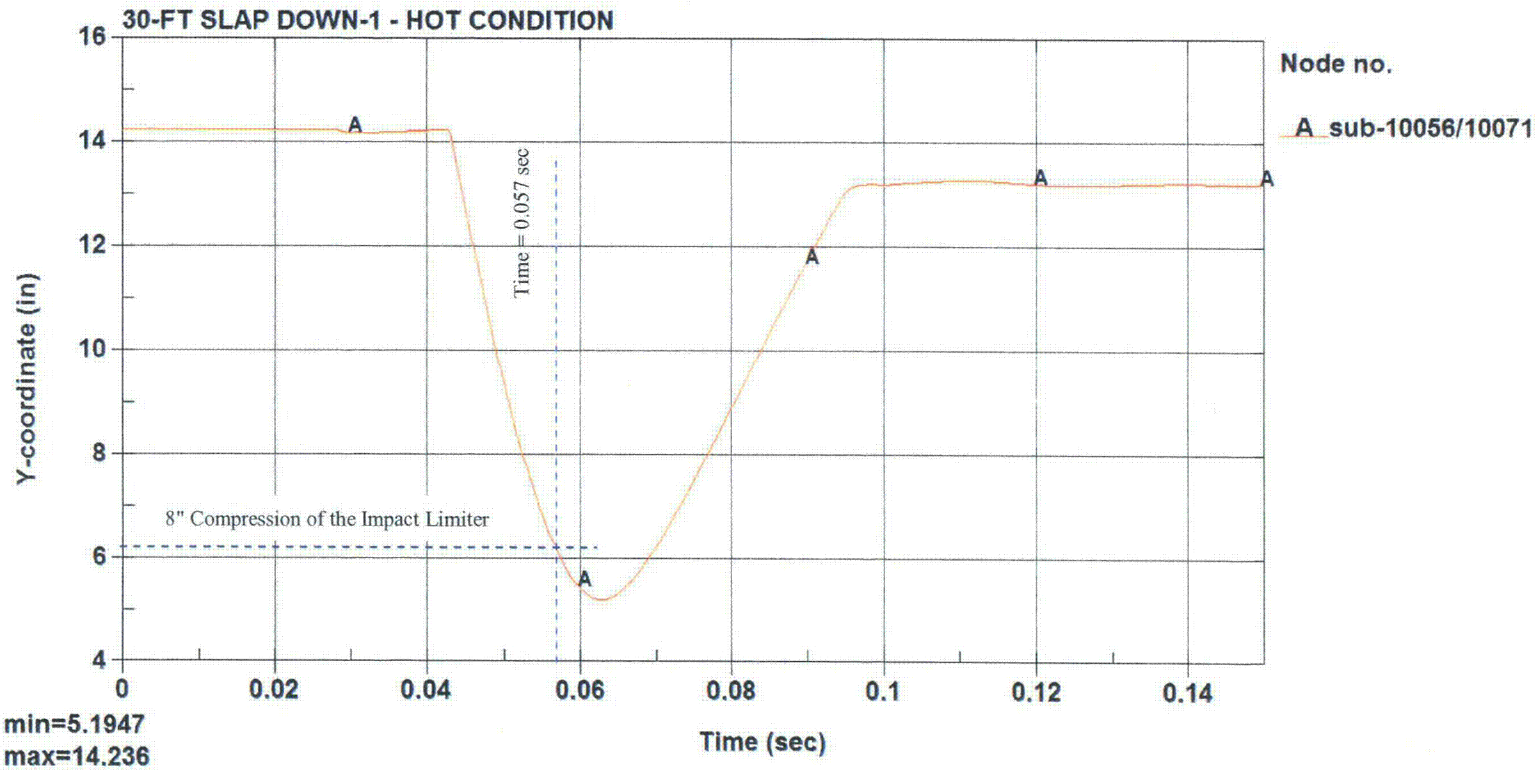


Figure 13
Impact Limiter Deformation Time-History for Slapdown-1 in Hot Environment
(ST-557 Reference 8, Figure 95)

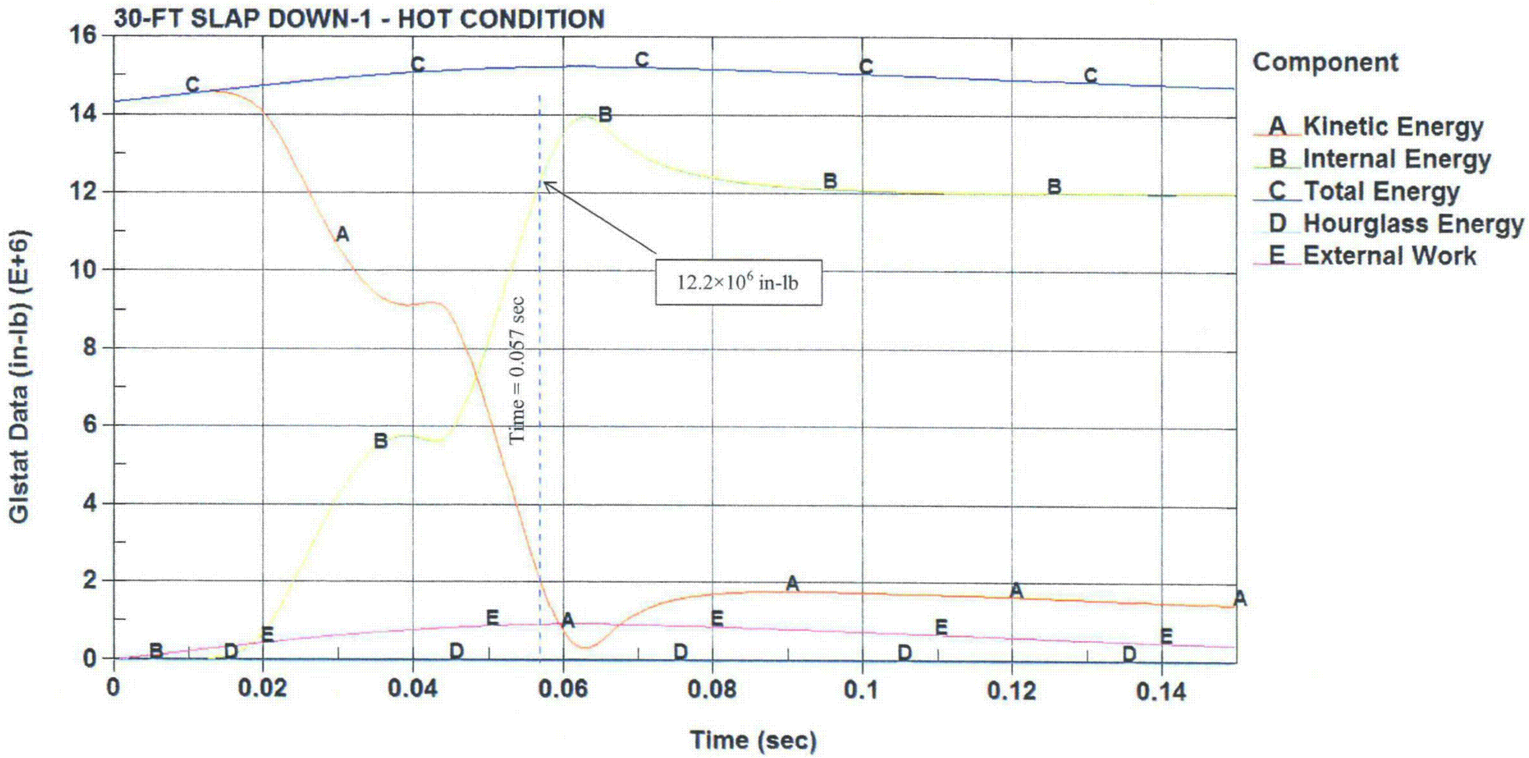


Figure 14
Impact Limiter Internal Energy Time-History for Slapdown-1 in Hot Environment
(ST-557 Reference 8, Figure 92)

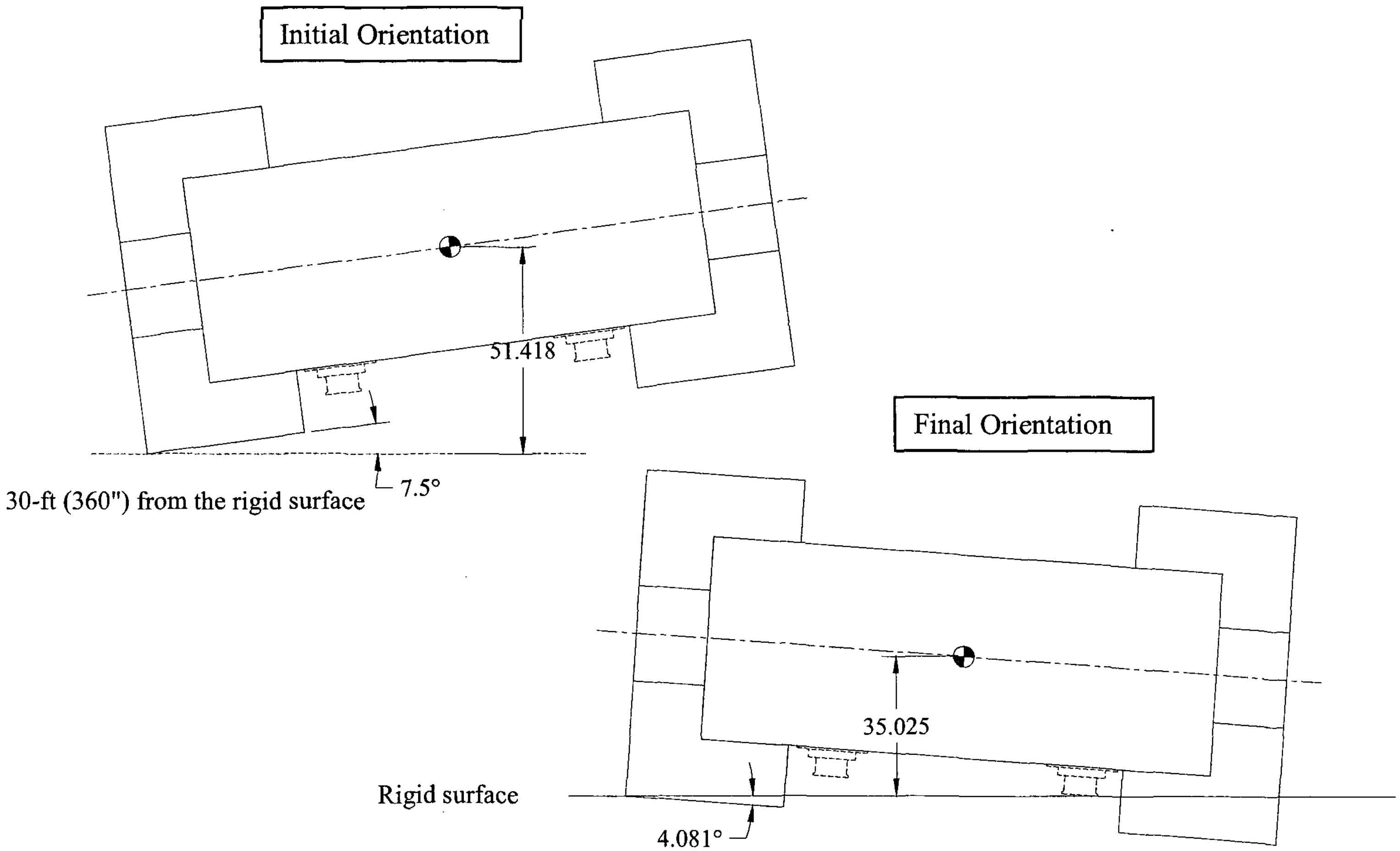


Figure 15
C.G. Location of the Package Before and After the Slapdown-1 Drop Test

Appendix 1

Printout of the ANSYS Model Data

(18 Pages)

ANSYS Model Sample Print-Out

Scenario 1: Puncture Drop on the Sidewall

```
    ***** TITLES *****

 *** YOU ARE IN   ANSYS - ENGINEERING ANALYSIS SYSTEM ***
 ANSYS Mechanical/Emag
 RELEASE  11.0SP1    UPDATE 20070830    CUSTOMER  00222442

 INITIAL JOBNAME = file
 CURRENT JOBNAME = file

 Current Working Directory: D:\Ansys Analyses\3-60B\Puncture Drop on Wall

 TITLE= Puncture Drop on Cask Sidewall

 MENULIST File: C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\UIDL\menulist110.ans

                          G L O B A L   S T A T U S

 ANSYS - Engineering Analysis System            Jun 17, 2009          08:48
 Release 11.0SP1              00222442                 WINDOWS x64  Version

 Current working directory: D:\Ansys Analyses\3-60B\Puncture Drop on Wall


 MENULIST File: C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\UIDL\menulist110.ans

 Product(s) enabled: ANSYS Mechanical/Emag


 Total connect time. . . . .   0 hours  1 minutes
 Total CP usage. . . . . . .   0 hours  0 minutes  2.4 seconds

 J O B   I N F O R M A T I O N -------------------------------------------

Puncture Drop on Cask Sidewall

 Current jobname . . . . . .file
 Initial jobname . . . . . .file

 Units . . . . . . . . . . .unknown

                              Available                Used
 Scratch Memory Space. . . .   4796.000 mb           6.538 mb (  0.1%)
 Database space  . . . . . . 1048572.000 mb         29.115 mb (  0.0%)

 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\uidl\UIMENU.GRN
 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\uidl\UIFUNC1.GRN
 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\uidl\UIFUNC2.GRN
 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\uidl\MECHTOOL.AUI
 Beta features . . . . . . .are not shown in the user interface

 M O D E L   I N F O R M A T I O N -------------------------------------------

 Solid model summary:

                              Largest         Number        Number
                               Number         Defined       Selected
 Keypoints . . . . . . . . .     33             33             15
```

Lines	47	47	22
Areas	23	23	11
Volumes	4	4	2

Finite element model summary:

	Largest Number	Number Defined	Number Selected
Nodes	25932	18541	4725
Elements.	5250	5019	800
Element types	9	9	n.a.
Real constant sets.	14	10	n.a.
Material property sets. . .	3	3	n.a.
Coupling.	0	0	n.a.
Constraint equations. . . .	0	0	n.a.
Master DOFs	0	0	n.a.
Dynamic gap conditions. . .	0	0	n.a.

B O U N D A R Y   C O N D I T I O N   I N F O R M A T I O N -----------------

	Number Defined
Constraints on nodes.	2123
Constraints on keypoints.	0
Constraints on lines.	0
Constraints on areas.	0
Forces on nodes	0
Forces on keypoints	0
Surface loads on elements	27
Number of element flagged surfaces . . .	0
Surface loads on lines.	0
Surface loads on areas.	0
Body loads on elements.	0
Body loads on nodes	0
Body loads on keypoints	0
Temperatures	
Uniform temperature.	0.000
Reference temperature.	0.000
Offset from absolute scale	0.000

	X	Y	Z
Linear acceleration	0.0000	0.0000	0.0000
Angular velocity (about global CS). . . .	0.0000	0.0000	0.0000
Angular acceleration (about global CS). .	0.0000	0.0000	0.0000
Location of reference CS.	0.0000	0.0000	0.0000
Angular velocity (about reference CS) . .	0.0000	0.0000	0.0000
Angular acceleration (about reference CS)	0.0000	0.0000	0.0000

R O U T I N E   I N F O R M A T I O N -------------------------------------

Current routine. . . . . .None (BEGIN level)

Active coordinate system . . . . 1 (Cylindrical)

Display coordinate system. . . . . . . 0 (Cartesian)

Analysis type. . . . . .Static (steady-state)

```
Active options for this analysis type:
   Large deformation effects . . . . .Not included
   Plasticity. . . . . . . . . . . . .Included
   Creep . . . . . . . . . . . . . . .Not included
   Equation solver to use. . . . . . .Sparse

Results file . . . . . . . . . . . .file.rst

Load step number . . . . . . . . . .     13

Number of substeps:
   Starting number of substeps . . . .    10
   Maximum number of substeps. . . . .   100
   Minimum number of substeps. . . . .     1
   Step change boundary conditions . .No

                  S O L U T I O N   O P T I O N S

  PROBLEM DIMENSIONALITY. . . . . . . . . . . . .3-D
  DEGREES OF FREEDOM. . . . . . UX   UY   UZ
  ANALYSIS TYPE . . . . . . . . . . . . . . . . .STATIC (STEADY-STATE)
  EQUATION SOLVER OPTION. . . . . . . . . . . . .SPARSE
  PLASTIC MATERIAL PROPERTIES INCLUDED. . . . . .YES
  NEWTON-RAPHSON OPTION . . . . . . . . . . . . .PROGRAM CHOSEN
  GLOBALLY ASSEMBLED MATRIX . . . . . . . . . . .SYMMETRIC

                 L O A D   S T E P   O P T I O N S

  LOAD STEP NUMBER. . . . . . . . . . . . . . . .    13
  TIME AT END OF THE LOAD STEP. . . . . . . . . .  16.000
  AUTOMATIC TIME STEPPING . . . . . . . . . . . .    ON
     INITIAL NUMBER OF SUBSTEPS . . . . . . . . .    10
     MAXIMUM NUMBER OF SUBSTEPS . . . . . . . . .   100
     MINIMUM NUMBER OF SUBSTEPS . . . . . . . . .     1
  MAXIMUM NUMBER OF EQUILIBRIUM ITERATIONS. . . .    15
  STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .    NO
  TERMINATE ANALYSIS IF NOT CONVERGED . . . . . .YES (EXIT)
  CONVERGENCE CONTROLS. . . . . . . . . . . . . .USE DEFAULTS
  COPY INTEGRATION POINT VALUES TO NODE . . . . .YES, FOR ELEMENTS WITH
                                                  ACTIVE MAT. NONLINEARITIES
  PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
  DATABASE OUTPUT CONTROLS
     ITEM     FREQUENCY   COMPONENT
      ALL        ALL


 LIST ELEMENT TYPES FROM      1 TO      9 BY      1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
 ANSYS Mechanical/Emag
 00222442         VERSION=WINDOWS x64   08:48:42  JUN 17, 2009 CP=      2.406

 Puncture Drop on Cask Sidewall


 ELEMENT TYPE      1 IS SOLID186     3-D 20-NODE STRUCTURAL SOLID    INOPR
  KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

 ELEMENT TYPE      2 IS TARGE170     3-D TARGET SEGMENT              INOPR
  KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

 ELEMENT TYPE      3 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
```

```
 KEYOPT(1-12)=    0  0  0    0  1  0    0  0  0    1  0  0       0

ELEMENT TYPE      4 IS TARGE170     3-D TARGET SEGMENT                INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

ELEMENT TYPE      5 IS CONTA174     3D 8-NODE SURF-SURF CONTACT       INOPR
 KEYOPT(1-12)=    0  0  0    0  1  0    0  0  0    1  0  0       0

ELEMENT TYPE      6 IS TARGE170     3-D TARGET SEGMENT                INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

ELEMENT TYPE      7 IS CONTA174     3D 8-NODE SURF-SURF CONTACT       INOPR
 KEYOPT(1-12)=    0  0  0    0  1  0    0  0  0    1  0  0       0

ELEMENT TYPE      8 IS TARGE170     3-D TARGET SEGMENT                INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

ELEMENT TYPE      9 IS CONTA174     3D 8-NODE SURF-SURF CONTACT       INOPR
 KEYOPT(1-12)=    0  0  0    0  1  0    0  0  1    1  0  0       0

CURRENT NODAL DOF SET IS  UX    UY    UZ
 THREE-DIMENSIONAL MODEL

LIST REAL SETS       1 TO      14 BY       1

REAL CONSTANT SET        3  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET        3  ITEMS   7 TO   12
   0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET        3  ITEMS  13 TO   18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET        3  ITEMS  19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET        4  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET        4  ITEMS   7 TO   12
   0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET        4  ITEMS  13 TO   18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET        4  ITEMS  19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET        5  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET        5  ITEMS   7 TO   12
   0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET        5  ITEMS  13 TO   18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET        5  ITEMS  19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET        6  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000
```

```
REAL CONSTANT SET        6  ITEMS   7 TO  12
    0.0000       0.0000      0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET        6  ITEMS  13 TO  18
    0.0000       0.0000       1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET        6  ITEMS  19 TO  24
    0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET        7  ITEMS   1 TO   6
    0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET        7  ITEMS   7 TO  12
    0.0000       0.0000      0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET        7  ITEMS  13 TO  18
    0.0000       0.0000       1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET        7  ITEMS  19 TO  24
    0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET        8  ITEMS   1 TO   6
    0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET        8  ITEMS   7 TO  12
    0.0000       0.0000      0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET        8  ITEMS  13 TO  18
    0.0000       0.0000       1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET        8  ITEMS  19 TO  24
    0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       11  ITEMS   1 TO   6
    0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       11  ITEMS   7 TO  12
    0.0000       0.0000      0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET       11  ITEMS  13 TO  18
    0.0000       0.0000       1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET       11  ITEMS  19 TO  24
    0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       12  ITEMS   1 TO   6
    0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       12  ITEMS   7 TO  12
    0.0000       0.0000      0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET       12  ITEMS  13 TO  18
    0.0000       0.0000       1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET       12  ITEMS  19 TO  24
    0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       13  ITEMS   1 TO   6
    0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       13  ITEMS   7 TO  12
    0.0000       0.0000      0.10000E+21   0.0000       1.0000       0.0000
```

```
REAL CONSTANT SET      13   ITEMS  13 TO  18
  0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      13   ITEMS  19 TO  24
  0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      14   ITEMS   1 TO   6
  0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      14   ITEMS   7 TO  12
  0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET      14   ITEMS  13 TO  18
  0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      14   ITEMS  19 TO  24
  0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

LIST MATERIALS        1 TO        3 BY        1
 PROPERTY= ALL

PROPERTY TABLE EX    MAT=        1  NUM. POINTS=  6
  TEMPERATURE     DATA     TEMPERATURE     DATA     TEMPERATURE      DATA
    70.000     0.28300E+08  100.00     0.28100E+08  200.00      0.27600E+08
    300.00     0.27000E+08  400.00     0.26500E+08  500.00      0.25800E+08

PROPERTY TABLE NUXY  MAT=        1  NUM. POINTS=  6
  TEMPERATURE     DATA     TEMPERATURE     DATA     TEMPERATURE      DATA
    70.000     0.30000      100.00     0.30000      200.00      0.30000
    300.00     0.30000      400.00     0.30000      500.00      0.30000

PROPERTY TABLE ALPX  MAT=        1  NUM. POINTS=  6   REFERENCE TEMP. =    0.00
  TEMPERATURE     DATA     TEMPERATURE     DATA     TEMPERATURE      DATA
    70.000     0.85000E-05  100.00     0.86000E-05  200.00      0.89000E-05
    300.00     0.92000E-05  400.00     0.95000E-05  500.00      0.97000E-05

PROPERTY TABLE DENS  MAT=        1  NUM. POINTS=  1
  TEMPERATURE     DATA     TEMPERATURE     DATA     TEMPERATURE      DATA
    0.0000     0.28300

PROPERTY TABLE MU    MAT=        1  NUM. POINTS=  1
  TEMPERATURE     DATA     TEMPERATURE     DATA     TEMPERATURE      DATA
    0.0000      0.0000

PROPERTY TABLE EMIS  MAT=        1  NUM. POINTS=  1
  TEMPERATURE     DATA     TEMPERATURE     DATA     TEMPERATURE      DATA
    0.0000     0.78886E-30

PROPERTY TABLE EX    MAT=        2  NUM. POINTS=  6
  TEMPERATURE     DATA     TEMPERATURE     DATA     TEMPERATURE      DATA
    70.000     0.29900E+08  100.00     0.29900E+08  200.00      0.29900E+08
    300.00     0.29900E+08  400.00     0.29900E+08  500.00      0.29900E+08

PROPERTY TABLE NUXY  MAT=        2  NUM. POINTS=  6
  TEMPERATURE     DATA     TEMPERATURE     DATA     TEMPERATURE      DATA
    70.000     0.30000      100.00     0.30000      200.00      0.30000
    300.00     0.30000      400.00     0.30000      500.00      0.30000

PROPERTY TABLE ALPX  MAT=        2  NUM. POINTS=  6   REFERENCE TEMP. =    0.00
  TEMPERATURE     DATA     TEMPERATURE     DATA     TEMPERATURE      DATA
    70.000     0.65000E-05  100.00     0.65000E-05  200.00      0.65000E-05
    300.00     0.65000E-05  400.00     0.65000E-05  500.00      0.65000E-05
```

```
PROPERTY TABLE DENS  MAT=        2  NUM. POINTS=  1
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
    0.0000      0.28300

PROPERTY TABLE EX     MAT=        3  NUM. POINTS=  8
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   -40.000      0.24600E+07 -20.000      0.24300E+07  70.000      0.22700E+07
    100.00      0.22100E+07  200.00      0.20100E+07  300.00      0.18500E+07
    400.00      0.17000E+07  500.00      0.15200E+07

PROPERTY TABLE NUXY  MAT=        3  NUM. POINTS=  6
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
    81.000      0.40000      212.00      0.40000      302.00      0.40000
    392.00      0.40000      513.00      0.40000      621.00      0.40000

PROPERTY TABLE ALPX  MAT=        3  NUM. POINTS=  8  REFERENCE TEMP. =    0.00
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   -40.000      0.15560E-04 -20.000      0.15650E-04  70.000      0.16060E-04
    100.00      0.16220E-04  200.00      0.16700E-04  300.00      0.17330E-04
    400.00      0.18160E-04  500.00      0.19120E-04

PROPERTY TABLE DENS  MAT=        3  NUM. POINTS=  1
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
    0.0000      0.41000

LIST DATA TABLE  ALL   FOR ALL MATERIALS

              BiKin Pl (BKIN) Table For Material     1

              1
  Temps    0.0000
Yld Strs   25000.
Tang Mod 0.13406E+06

              BiKin Pl (BKIN) Table For Material     3

              1
  Temps    0.0000
Yld Strs   4300.0
Tang Mod   4200.0

LIST NODAL SURFACE LOAD PRES FOR ALL SELECTED NODES
```

Scenario 2: Puncture Drop on the Lid

```
    ***** TITLES *****

*** YOU ARE IN   ANSYS - ENGINEERING ANALYSIS SYSTEM ***
ANSYS Mechanical/Emag
RELEASE  11.0SP1   UPDATE 20070830   CUSTOMER  00222442

INITIAL JOBNAME = file
CURRENT JOBNAME = file

Current Working Directory: G:\3-60B Rev 2\Puncture

TITLE= Puncture Drop on the Lid (Hot)

MENULIST File: C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\UIDL\menulist110.ans

                        G L O B A L   S T A T U S

ANSYS - Engineering Analysis System           Dec 07, 2007          10:10
Release 11.0SP1              00222442                 INTEL NT     Version

Current working directory: G:\3-60B Rev 2\Puncture


MENULIST File: C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\UIDL\menulist110.ans

Product(s) enabled: ANSYS Mechanical/Emag


Total connect time. . . . .   0 hours  1 minutes
Total CP usage. . . . . . .   0 hours  0 minutes  2.3 seconds

J O B   I N F O R M A T I O N -----------------------------------------------

Puncture Drop on the Lid (Hot)

 Current jobname . . . . . .file
 Initial jobname . . . . . .file

 Units . . . . . . . . . . .unknown

                              Available              Used
 Scratch Memory Space. . . .    256.000 mb          4.598 mb (  1.8%)
 Database space  . . . . . .  65535.750 mb          8.777 mb (  0.0%)

 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\uidl\UIMENU.GRN
 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\uidl\UIFUNC1.GRN
 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\uidl\UIFUNC2.GRN
 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\uidl\MECHTOOL.AUI
 Beta features . . . . . . .are not shown in the user interface

 M O D E L   I N F O R M A T I O N -----------------------------------------

 Solid model summary:

                              Largest        Number        Number
                               Number        Defined       Selected
 Keypoints . . . . . . . . .      0              0             0
 Lines . . . . . . . . . . .      0              0             0
 Areas . . . . . . . . . . .      0              0             0
 Volumes . . . . . . . . . .      0              0             0
```

```
Finite element model summary:

                              Largest        Number        Number
                              Number         Defined       Selected
Nodes . . . . . . . . . . .     3001           2879          2878
Elements. . . . . . . . . .     3946           2369          1522

Element types . . . . . . .       71             36          n.a.
Real constant sets. . . . .       71             29          n.a.
Material property sets. . .        3              3          n.a.

Coupling. . . . . . . . . .       82             30          n.a.
Constraint equations. . . .        0              0          n.a.
Master DOFs . . . . . . . .        0              0          n.a.
Dynamic gap conditions. . .        0              0          n.a.

B O U N D A R Y   C O N D I T I O N   I N F O R M A T I O N -----------------

                                         Number
                                         Defined
Constraints on nodes. . . . . . . . . . .  1196
Constraints on keypoints. . . . . . . . .     0
Constraints on lines. . . . . . . . . . .     0
Constraints on areas. . . . . . . . . . .     0

Forces on nodes . . . . . . . . . . . . .     0
Forces on keypoints . . . . . . . . . . .     0

Surface loads on elements . . . . . . . .     1
Number of element flagged surfaces  . . .     0
Surface loads on lines. . . . . . . . . .     0
Surface loads on areas. . . . . . . . . .     0

Body loads on elements. . . . . . . . . .     0
Body loads on nodes . . . . . . . . . . .  2878
Body loads on keypoints . . . . . . . . .     0

Temperatures
   Uniform temperature. . . . . . . . . .  -20.000
   Reference temperature. . . . . . . . .   70.000
   Offset from absolute scale . . . . . .  460.000

                                              X          Y          Z
Linear acceleration . . . . . . . . . . .  0.0000     0.0000     22.390
Angular velocity (about global CS). . . .  0.0000     0.0000     0.0000
Angular acceleration (about global CS). .  0.0000     0.0000     0.0000
Location of reference CS. . . . . . . . .  0.0000     0.0000     0.0000
Angular velocity (about reference CS) . .  0.0000     0.0000     0.0000
Angular acceleration (about reference CS)  0.0000     0.0000     0.0000

R O U T I N E   I N F O R M A T I O N ------------------------------------

Current routine. . . . . . . . . . . .Preprocessing (PREP7)

Active coordinate system . . . . . . .  1 (Cylindrical)

Display coordinate system. . . . . . .  0 (Cartesian)

Current element attributes:
   Type number . . . . . . . . . . . .   71   (COMBIN14)
   Real number . . . . . . . . . . . .   71
   Material number . . . . . . . . . .    1
```

```
   Element coordinate system number. .     0

Current mesher type. . . . . . . . . .based on default element shape

Current element meshing shape 2D . . .use default element shape.

Current element meshing shape 3D . . .use default element shape.

SmrtSize Level  . . . . . . . . . . . . OFF

Global element size. . . . . . . . . .     0 divisions per line

Active coordinate system . . . . . . .   1 (Cylindrical)

Display coordinate system. . . . . . .   0 (Cartesian)

Analysis type. . . . . . . . . . . . .Static (steady-state)

Active options for this analysis type:
   Large deformation effects . . . . .Not included
   Plasticity. . . . . . . . . . . . .Not included
   Creep . . . . . . . . . . . . . . .Not included
   Equation solver to use. . . . . . .Program Chosen

Results file . . . . . . . . . . . . .file.rst

Load step number . . . . . . . . . .     2

Number of substeps . . . . . . . . .     1
   Step change boundary conditions . .No

                      S O L U T I O N   O P T I O N S

  PROBLEM DIMENSIONALITY. . . . . . . . . . . . .3-D
  DEGREES OF FREEDOM. . . . . . UX   UY   UZ   TEMP
  ANALYSIS TYPE . . . . . . . . . . . . . . . . .STATIC (STEADY-STATE)
  OFFSET TEMPERATURE FROM ABSOLUTE ZERO . . . . .  460.00
  NEWTON-RAPHSON OPTION . . . . . . . . . . . . .PROGRAM CHOSEN
  GLOBALLY ASSEMBLED MATRIX . . . . . . . . . . .SYMMETRIC

                      L O A D   S T E P   O P T I O N S

  LOAD STEP NUMBER. . . . . . . . . . . . . . . .     2
  TIME AT END OF THE LOAD STEP. . . . . . . . . .  3.0000
  NUMBER OF SUBSTEPS. . . . . . . . . . . . . . .     1
  MAXIMUM NUMBER OF EQUILIBRIUM ITERATIONS. . . .    15
  STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .    NO
  TERMINATE ANALYSIS IF NOT CONVERGED . . . . . .YES (EXIT)
  CONVERGENCE CONTROLS
     LABEL   REFERENCE    TOLERANCE  NORM     MINREF
      F      0.1000       0.1000E-02   2     -1.000
  INERTIA LOADS                        X           Y           Z
     ACEL . . . . . . . . . . . . . 0.0000      0.0000      22.390
  PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
  DATABASE OUTPUT CONTROLS
     ITEM     FREQUENCY   COMPONENT
     BASI        ALL


LIST ELEMENT TYPES FROM       1 TO      71 BY       1

ELEMENT TYPE       1 IS SOLID185      3-D 8-NODE STRUCTURAL SOLID     INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0          0
```

```
ELEMENT TYPE       2 IS SHELL41      MEMBRANE SHELL                  INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE       3 IS SOLSH190     3-D 8-NODE SOLID SHELL          INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      14 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      15 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    2  1  0    0  0  1    0  0  1        0

ELEMENT TYPE      16 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      17 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  2  0    2  3  0    0  0  1    2  0  6        0

ELEMENT TYPE      18 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      19 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    2  2  0    0  0  1    2  0  5        0

ELEMENT TYPE      20 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      21 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    2  1  0    0  0  1    2  0  3        0

ELEMENT TYPE      22 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      23 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    2  3  0    0  0  1    2  0  0        0

ELEMENT TYPE      24 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      25 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    2  3  0    0  0  1    2  0  0        0

ELEMENT TYPE      26 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      27 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    2  3  0    0  0  1    2  0  0        0

ELEMENT TYPE      28 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      29 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    2  3  0    0  0  1    2  0  0        0

ELEMENT TYPE      30 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      31 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    2  3  0    0  0  1    2  0  0        0

ELEMENT TYPE      53 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0
```

```
ELEMENT TYPE      54 IS CONTA175     NODE-TO-SURFACE CONTACT          INOPR
 KEYOPT(1-12)=    0  2  0    0  3  0    0  0  1    2  0  5        0

ELEMENT TYPE      57 IS TARGE170     3-D TARGET SEGMENT               INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      58 IS CONTA174     3D 8-NODE SURF-SURF CONTACT      INOPR
 KEYOPT(1-12)=    0  0  0    2  3  0    0  0  1    2  0  1        0

ELEMENT TYPE      61 IS TARGE170     3-D TARGET SEGMENT               INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      62 IS CONTA174     3D 8-NODE SURF-SURF CONTACT      INOPR
 KEYOPT(1-12)=    0  0  0    2  3  0    0  0  1    2  0  0        0

ELEMENT TYPE      63 IS TARGE170     3-D TARGET SEGMENT               INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      64 IS CONTA174     3D 8-NODE SURF-SURF CONTACT      INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  0        0

ELEMENT TYPE      65 IS TARGE170     3-D TARGET SEGMENT               INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      66 IS CONTA175     NODE-TO-SURFACE CONTACT          INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  0        0

ELEMENT TYPE      67 IS TARGE170     3-D TARGET SEGMENT               INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      68 IS CONTA175     NODE-TO-SURFACE CONTACT          INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  0        0

ELEMENT TYPE      69 IS TARGE170     3-D TARGET SEGMENT               INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE      70 IS CONTA175     NODE-TO-SURFACE CONTACT          INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  0        0

ELEMENT TYPE      71 IS COMBIN14     SPRING-DAMPER                    INOPR
 KEYOPT(1-12)=    0  3  0    0  0  0    0  0  0    0  0  0        0

CURRENT NODAL DOF SET IS  UX    UY    UZ    TEMP
 THREE-DIMENSIONAL MODEL

LIST REAL SETS        1 TO       71 BY        1

REAL CONSTANT SET      23  ITEMS    1 TO    6
   1.0000      0.33056E-14   0.0000        0.0000        0.0000        0.0000

REAL CONSTANT SET      24  ITEMS    1 TO    6
   0.0000        0.0000        0.0000        0.0000        0.0000        0.0000

REAL CONSTANT SET      24  ITEMS    7 TO   12
   0.0000        0.0000        0.0000        0.0000        0.0000        0.0000

REAL CONSTANT SET      24  ITEMS   13 TO   13
  0.33300

REAL CONSTANT SET      27  ITEMS    1 TO    6
   1.0000      0.33056E-14   0.0000        0.0000        0.0000        0.0000
```

```
REAL CONSTANT SET       28  ITEMS    1 TO    6
   0.0000       0.0000       0.0000       0.0000       0.0000       0.0000

REAL CONSTANT SET       28  ITEMS    7 TO   12
   0.0000       0.0000       0.0000       0.0000       0.0000       0.0000

REAL CONSTANT SET       28  ITEMS   13 TO   13
  0.33300

REAL CONSTANT SET       32  ITEMS    1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       32  ITEMS    7 TO   12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       32  ITEMS   13 TO   18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET       32  ITEMS   19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       33  ITEMS    1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       33  ITEMS    7 TO   12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       33  ITEMS   13 TO   18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET       33  ITEMS   19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       34  ITEMS    1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       34  ITEMS    7 TO   12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       34  ITEMS   13 TO   18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET       34  ITEMS   19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       35  ITEMS    1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       35  ITEMS    7 TO   12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       35  ITEMS   13 TO   18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET       35  ITEMS   19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       36  ITEMS    1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       36  ITEMS    7 TO   12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000
```

```
REAL CONSTANT SET      36  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      36  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      37  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      37  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET      37  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      37  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      38  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      38  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET      38  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      38  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      39  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      39  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET      39  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      39  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      40  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      40  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET      40  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      40  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      42  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      42  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET      42  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000
```

```
REAL CONSTANT SET      42  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000       0.0000       1.0000

REAL CONSTANT SET      43  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000      0.0000       0.0000

REAL CONSTANT SET      43  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      43  ITEMS  13 TO  18
   0.0000       0.0000       1.0000      0.0000       1.0000      0.50000

REAL CONSTANT SET      43  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000       0.0000       1.0000

REAL CONSTANT SET      44  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000      0.0000       0.0000

REAL CONSTANT SET      44  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      44  ITEMS  13 TO  18
   0.0000       0.0000       1.0000      0.0000       1.0000      0.50000

REAL CONSTANT SET      44  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000       0.0000       1.0000

REAL CONSTANT SET      45  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000      0.0000       0.0000

REAL CONSTANT SET      45  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      45  ITEMS  13 TO  18
   0.0000       0.0000       1.0000      0.0000       1.0000      0.50000

REAL CONSTANT SET      45  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000       0.0000       1.0000

REAL CONSTANT SET      46  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000      0.0000       0.0000

REAL CONSTANT SET      46  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      46  ITEMS  13 TO  18
   0.0000       0.0000       1.0000      0.0000       1.0000      0.50000

REAL CONSTANT SET      46  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000       0.0000       1.0000

REAL CONSTANT SET      47  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000      0.0000       0.0000

REAL CONSTANT SET      47  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      47  ITEMS  13 TO  18
   0.0000       0.0000       1.0000      0.0000       1.0000      0.50000

REAL CONSTANT SET      47  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000       0.0000       1.0000
```

```
REAL CONSTANT SET      48  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000        0.0000        0.0000

REAL CONSTANT SET      48  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21   0.0000         1.0000        0.0000

REAL CONSTANT SET      48  ITEMS  13 TO  18
   0.0000       0.0000       1.0000      0.0000         1.0000       0.50000

REAL CONSTANT SET      48  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000         0.0000        1.0000

REAL CONSTANT SET      50  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000        0.0000        0.0000

REAL CONSTANT SET      50  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21   0.0000         1.0000        0.0000

REAL CONSTANT SET      50  ITEMS  13 TO  18
   0.0000       0.0000       1.0000      0.0000         1.0000       0.50000

REAL CONSTANT SET      50  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000         0.0000        1.0000

REAL CONSTANT SET      51  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000        0.0000        0.0000

REAL CONSTANT SET      51  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21   0.0000         1.0000        0.0000

REAL CONSTANT SET      51  ITEMS  13 TO  18
   0.0000       0.0000       1.0000      0.0000         1.0000       0.50000

REAL CONSTANT SET      51  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000         0.0000        1.0000

REAL CONSTANT SET      52  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000        0.0000        0.0000

REAL CONSTANT SET      52  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21   0.0000         1.0000        0.0000

REAL CONSTANT SET      52  ITEMS  13 TO  18
   0.0000       0.0000       1.0000      0.0000         1.0000       0.50000

REAL CONSTANT SET      52  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000         0.0000        1.0000

REAL CONSTANT SET      53  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000        0.0000        0.0000

REAL CONSTANT SET      53  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21   0.0000         1.0000        0.0000

REAL CONSTANT SET      53  ITEMS  13 TO  18
   0.0000       0.0000       1.0000      0.0000         1.0000       0.50000

REAL CONSTANT SET      53  ITEMS  19 TO  24
   0.0000       1.0000       1.0000      0.0000         0.0000        1.0000

REAL CONSTANT SET      54  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000        0.0000        0.0000
```

```
REAL CONSTANT SET      54  ITEMS   7 TO  12
   0.0000      0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      54  ITEMS  13 TO  18
   0.0000      0.0000      1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET      54  ITEMS  19 TO  24
   0.0000      1.0000      1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      55  ITEMS   1 TO   6
   0.0000      0.0000      1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      55  ITEMS   7 TO  12
   0.0000      0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      55  ITEMS  13 TO  18
   0.0000      0.0000      1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET      55  ITEMS  19 TO  24
   0.0000      1.0000      1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      55  ITEMS  25 TO  25
   10.000

REAL CONSTANT SET      56  ITEMS   1 TO   6
   0.0000      0.0000      1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      56  ITEMS   7 TO  12
   0.0000      0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      56  ITEMS  13 TO  18
   0.0000      0.0000      1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET      56  ITEMS  19 TO  24
   0.0000      1.0000      1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      56  ITEMS  25 TO  25
   10.000

REAL CONSTANT SET      57  ITEMS   1 TO   6
   0.0000      0.0000      1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      57  ITEMS   7 TO  12
   0.0000      0.0000     0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      57  ITEMS  13 TO  18
   0.0000      0.0000      1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET      57  ITEMS  19 TO  24
   0.0000      1.0000      1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      57  ITEMS  25 TO  25
   10.000

REAL CONSTANT SET      71  ITEMS   1 TO   6
   1000.0      0.0000      0.0000       0.0000       0.0000       0.0000

LIST MATERIALS        1 TO       3 BY       1
 PROPERTY= ALL

PROPERTY TABLE EX    MAT=       1  NUM. POINTS=  6
  TEMPERATURE      DATA    TEMPERATURE      DATA    TEMPERATURE      DATA
    70.000     0.28300E+08  100.00      0.28100E+08  200.00      0.27600E+08
```

```
   300.00       0.27000E+08  400.00      0.26500E+08  500.00      0.25800E+08

PROPERTY TABLE NUXY  MAT=        1  NUM. POINTS=  6
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   70.000       0.30000      100.00      0.30000       200.00      0.30000
   300.00       0.30000      400.00      0.30000       500.00      0.30000

PROPERTY TABLE ALPX  MAT=        1  NUM. POINTS=  6   REFERENCE TEMP. =   70.00
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   70.000       0.85000E-05  100.00      0.86000E-05  200.00      0.89000E-05
   300.00       0.92000E-05  400.00      0.95000E-05  500.00      0.97000E-05

PROPERTY TABLE DENS  MAT=        1  NUM. POINTS=  1
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   0.0000       0.28300

PROPERTY TABLE MU    MAT=        1  NUM. POINTS=  1
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   0.0000        0.0000

PROPERTY TABLE EMIS  MAT=        1  NUM. POINTS=  1
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   0.0000        0.0000

PROPERTY TABLE EX    MAT=        2  NUM. POINTS=  6
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   70.000       0.29900E+08  100.00      0.29900E+08  200.00      0.29900E+08
   300.00       0.29900E+08  400.00      0.29900E+08  500.00      0.29900E+08

PROPERTY TABLE NUXY  MAT=        2  NUM. POINTS=  6
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   70.000       0.30000      100.00      0.30000       200.00      0.30000
   300.00       0.30000      400.00      0.30000       500.00      0.30000

PROPERTY TABLE ALPX  MAT=        2  NUM. POINTS=  6   REFERENCE TEMP. =   70.00
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   70.000       0.65000E-05  100.00      0.65000E-05  200.00      0.65000E-05
   300.00       0.65000E-05  400.00      0.65000E-05  500.00      0.65000E-05

PROPERTY TABLE DENS  MAT=        2  NUM. POINTS=  1
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   0.0000       0.28300

PROPERTY TABLE EX    MAT=        3  NUM. POINTS=  8
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
  -40.000       0.24600E+07 -20.000      0.24300E+07  70.000      0.22700E+07
   100.00       0.22100E+07  200.00      0.20100E+07  300.00      0.18500E+07
   400.00       0.17000E+07  500.00      0.15200E+07

PROPERTY TABLE NUXY  MAT=        3  NUM. POINTS=  6
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   81.000       0.40000      212.00      0.40000       302.00      0.40000
   392.00       0.40000      513.00      0.40000       621.00      0.40000

PROPERTY TABLE ALPX  MAT=        3  NUM. POINTS=  8   REFERENCE TEMP. =   70.00
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
  -40.000       0.15560E-04 -20.000      0.15650E-04  70.000      0.16060E-04
   100.00       0.16220E-04  200.00      0.16700E-04  300.00      0.17330E-04
   400.00       0.18160E-04  500.00      0.19120E-04

PROPERTY TABLE DENS  MAT=        3  NUM. POINTS=  1
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
   0.0000       0.41000
```

Appendix 2

Electronic Data on CDROM

(1 Page & 1 CDROM)