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TRANSIENT THERMAL STRESS RECOVERY FOR STRUCTURAL MODELS

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ABSTRACT

A method for computing transient thermal stress vectors from temperature vectors is described. The three step procedure involves the use of NASTRAN to generate an influence coefficient matrix which relates temperatures to stresses in the structural model. The transient thermal stresses are then recovered and sorted for maximum and minimum values. Verification data for the procedure is also provided.

1.0 INTRODUCTION

There are many occasions when the stresses produced by transient thermal events must be considered. The ascent, on-orbit, and descent phases of a Spacelab mission produce large temperature gradients on the Cargo Element. A method for recovering the thermal stresses produced by these events was developed by the Structural Analysis Group at McDonnell Douglas Space Systems Company-Huntsville (MDSSC-HSV), and has been used for more than six years in Spacelab Evaluation.

Because this method was somewhat unhandy to use, only a limited number of temperature distributions could be run. These were generally chosen on the basis of temperature or temperature difference extremes. Unfortunately, there is no proven relationship between "worst stresses" and "worst temperatures" or "worst temperature differences" for the complex models with which Spacelab has to deal. It was therefore decided to develop a process that would transform transient temperature vectors (which are separately calculated) directly into stress vectors that could then be sorted for maximum and minimum (Max/Min) values.

Section 2 presents the theory used in the procedure, Section 3 describes the procedure, Section 4 presents verification results, and Section 5 contains the conclusions.

2.0 THEORY

The method described assumes that the thermal strains, and hence stresses are linearly proportional to the temperatures. The method, therefore, is not applicable to models having temperature or stress dependent material properties.

An influence coefficient matrix, [TRAS], to transform the temperatures at a models n grids into m stresses can be developed as follows. A temperature of one unit above the reference is applied to a grid in the model while the remaining n-1 grids are held at the reference temperature. The resulting m stresses are then recovered. This is repeated for all n grids in the model. The resulting n sets of stresses are then assembled as columns to form an m by n influence coefficient matrix, [TRAS], that can be used to transform temperature vectors into stress vectors. The transformation is as follows:

$$[STMHST] = [TRAS][TEMPS] \qquad (1)$$

Where;

[STMHST] = Stresses in the finite element model (time history).

[TRAS] = Linear transformation (influence coefficient) from temperatures to stresses.

[TEMPS] = Temperatures at the grids (time history).

Equation (1) is used to recover transient stress vectors from transient temperature vectors.

3.0 PROCEDURE

The procedure used to recover maximum and minimum thermal stresses is divided into three steps. The first step is to generate the influence coefficient matrix [TRAS]. The transient stresses are recovered using equation (1) in the second step. The transient thermal stresses are then sorted for Max/Min data in the third step. Each of these three steps will be described below.

3.1 Step 1 - Generation of The Influence Coefficient Matrix [TRAS]

NASTRAN is used to generate [TRAS] as described in Section 2. NASTRAN Subcase commands are used to accomplish this step with each subcase corresponding to a grid in the model. It should be noted that NASTRAN can handle a maximum of sixty-six temperature load cases. A model having more than sixty-six grids will, therefore, require multiple runs and subsequent merging of the output data. An example of a NASTRAN control deck to generate [TRAS] for the verification model described in Section 4 is shown in Figure 1. The DUMMOD5 module is used to convert the OES1 table into a matrix data block which is then written to a file using the OUTPUT5 module. The extraneous rows (fiber distances, safety margins, etc.) of [TRAS] are then removed using a specially developed FORTRAN code.

3.2 Step 2 - Recover Transient Thermal Stress Vectors From Temperature Vectors

The transient temperature vectors must now be obtained. At MDSSC-Huntsville, the thermal analyses are performed using SINDA. A FORTRAN code has been written to access the SINDA output file and recover the desired temperatures along with the corresponding time vectors. The temperature and time data is written in OUTPUT5 format. Care should be taken to ensure that the row order of the temperature vectors is compatible with the column order of [TRAS].

Equation (1) is then used to recover the transient thermal stress vectors. This is easily accomplished in a simple DMAP run using the MPYAD module. The resulting thermal stress vectors and time vector are written to a file using the OUTPUT5 module.

3.3 Step 3 - Sort Thermal Stress Vectors For Maximum and Minimum Data.

The transient thermal stress vectors are now sorted for Max/Min data. This step is performed using a specialized FORTRAN code. This code can search multiple time histories allowing composite Max/Min tables to be obtained. An example of output from this program for the Spacelab Multipurpose Experiment Support Structure (MPESS) is shown in Table 1. The data in Table 1 was obtained from actual temperature vectors for a Spacelab mission and encompasses ascent, orbit, and descent.

4.0 VERIFICATION

In order to verify that the procedure is working correctly, a test case was performed. A simple rectangular plate model was constructed using QUAD4 and BAR elements. A plot of the plate model is presented in Figure 2 and the Bulk Data is shown in Figure 3. The model has thirty-three grids and is homogeneous. A temperature gradient (see Figure 4) was applied to the model and the resulting stresses in four elements were recovered using NASTRAN directly. The results are presented in Figure 5. The transient thermal stress recovery procedure was then used to calculate stresses due to the same temperature gradient and the results are shown in Table 2.

It can be seen from Figure 5 and Table 2 that the results are the same. This indicates that using [TRAS] to perform the thermal stress recovery produces the same results as using NASTRAN directly.

5.0 CONCLUSION

A procedure has been developed to recover thermal stresses in a NASTRAN model directly from temperatures output by a thermal model. Because the procedure uses a linear transformation matrix rather than a computer program, entire thermal stress time histories may be efficiently obtained and scanned for Max/Min thermal stress data. Tabular output of the Max/Min data is then produced. A test case has been executed and the results indicate that the procedure functions correctly.

```
NASTRAN TITLEOPT=0
$
$ RUN TO GENERATE INFLUENCE COEFF. MATRIX FOR THERMAL STRESS RECOVERY.
$
$
$
$
ID  CHECKOUT PLATE
APP DISP
SOL 1,7
TIME 999
DIAG 13,14,21,22,26,42
$
$   WRITE OUT ELEMENT STRESS/FORCE MATRICES
$     WHERE;
$       OES1=STRESSES
$       OEF1=FORCES
$       I=# OF ELEMENTS FOR WHICH STRESSES/FORCES ARE BEING RECOVERED
$
ALTER 106
DUMMOD5  OES1,,,,/ELSEU,,,,/C,N,44/////C,N,1/C,N,1 $
OUTPUT5  ELSEU,,,,//0/15//0 $
OUTPUT5  ,,,,//-9/15//0 $
ENDALTER
CEND
$
TITLE =  ANALYSIS OF PLATE
SUBTITLE = RUN TO GENERATE INFLUENCE COEFFICIENT MATRIX
LABEL = PLATE
MAXLINES = 99999999
  SPC=100
$
SUBCASE 1
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 1
  TEMP(LOAD) = 1
  ELSTRESS=ALL
$
SUBCASE 2
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 2
  TEMP(LOAD) = 2
  ELSTRESS=ALL
$
SUBCASE 3
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 3
  TEMP(LOAD) = 3
  ELSTRESS=ALL
$
SUBCASE 4
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 4
  TEMP(LOAD) = 4
  ELSTRESS=ALL
$
SUBCASE 5
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 5
```

Figure 1. NASTRAN Control Deck to Generate [TRAS] for the Verification Plate Model

```
  TEMP(LOAD) = 5
  ELSTRESS=ALL
$
SUBCASE 6
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 6
  TEMP(LOAD) = 6
  ELSTRESS=ALL
$
SUBCASE 7
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 7
  TEMP(LOAD) = 7
  ELSTRESS=ALL
$
SUBCASE 8
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 8
  TEMP(LOAD) = 8
  ELSTRESS=ALL
$
SUBCASE 9
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 9
  TEMP(LOAD) = 9
  ELSTRESS=ALL
$
SUBCASE 10
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 10
  TEMP(LOAD) = 10
  ELSTRESS=ALL
$
SUBCASE 11
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 11
  TEMP(LOAD) = 11
  ELSTRESS=ALL
$
SUBCASE 12
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 12
  TEMP(LOAD) = 12
  ELSTRESS=ALL
$
SUBCASE 13
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 13
  TEMP(LOAD) = 13
  ELSTRESS=ALL
$
SUBCASE 14
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 14
  TEMP(LOAD) = 14
  ELSTRESS=ALL
$
SUBCASE 15
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 15
  TEMP(LOAD) = 15
  ELSTRESS=ALL
$
SUBCASE 16
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 16
```

Figure 1. NASTRAN Control Deck to Generate [TRAS] for the Verification Plate Model (Continued)

```
  TEMP(LOAD) = 16
  ELSTRESS=ALL
$
SUBCASE 17
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 17
  TEMP(LOAD) = 17
  ELSTRESS=ALL
$
SUBCASE 18
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 18
  TEMP(LOAD) = 18
  ELSTRESS=ALL
$
SUBCASE 19
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 19
  TEMP(LOAD) = 19
  ELSTRESS=ALL
$
SUBCASE 20
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 20
  TEMP(LOAD) = 20
  ELSTRESS=ALL
$
SUBCASE 21
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 21
  TEMP(LOAD) = 21
  ELSTRESS=ALL
$
SUBCASE 22
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 22
  TEMP(LOAD) = 22
  ELSTRESS=ALL
$
SUBCASE 23
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 23
  TEMP(LOAD) = 23
  ELSTRESS=ALL
$
SUBCASE 24
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 24
  TEMP(LOAD) = 24
  ELSTRESS=ALL
$
SUBCASE 25
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 25
  TEMP(LOAD) = 25
  ELSTRESS=ALL
$
SUBCASE 26
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 26
  TEMP(LOAD) = 26
  ELSTRESS=ALL
$
SUBCASE 27
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 27
```

Figure 1. NASTRAN Control Deck to Generate [TRAS] for the Verification Plate Model (Continued)

```
  TEMP(LOAD) = 27
  ELSTRESS=ALL
$
SUBCASE 28
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 28
  TEMP(LOAD) = 28
  ELSTRESS=ALL
$
SUBCASE 29
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 29
  TEMP(LOAD) = 29
  ELSTRESS=ALL
$
SUBCASE 30
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 30
  TEMP(LOAD) = 30
  ELSTRESS=ALL
$
SUBCASE 31
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 31
  TEMP(LOAD) = 31
  ELSTRESS=ALL
$
SUBCASE 32
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 32
  TEMP(LOAD) = 32
  ELSTRESS=ALL
$
SUBCASE 33
  LABEL = APPLY A 1 DEGREE ABOVE REF. TEMP. TO GRID 33
  TEMP(LOAD) = 33
  ELSTRESS=ALL
$
BEGIN BULK
$
SPC1    100     123456  1
$
TEMP    1       1       71.0
TEMPD   1       70.0
TEMP    2       2       71.0
TEMPD   2       70.0
TEMP    3       3       71.0
TEMPD   3       70.0
TEMP    4       4       71.0
TEMPD   4       70.0
TEMP    5       5       71.0
TEMPD   5       70.0
TEMP    6       6       71.0
TEMPD   6       70.0
TEMP    7       7       71.0
TEMPD   7       70.0
TEMP    8       8       71.0
TEMPD   8       70.0
TEMP    9       9       71.0
TEMPD   9       70.0
```

Figure 1. NASTRAN Control Deck to Generate [TRAS] for the Verification Plate Model (Continued)

```
TEMP     10     10     71.0
TEMPD    10     70.0
TEMP     11     11     71.0
TEMPD    11     70.0
TEMP     12     12     71.0
TEMPD    12     70.0
TEMP     13     13     71.0
TEMPD    13     70.0
TEMP     14     14     71.0
TEMPD    14     70.0
TEMP     15     15     71.0
TEMPD    15     70.0
TEMP     16     16     71.0
TEMPD    16     70.0
TEMP     17     17     71.0
TEMPD    17     70.0
TEMP     18     18     71.0
TEMPD    18     70.0
TEMP     19     19     71.0
TEMPD    19     70.0
TEMP     20     20     71.0
TEMPD    20     70.0
TEMP     21     21     71.0
TEMPD    21     70.0
TEMP     22     22     71.0
TEMPD    22     70.0
TEMP     23     23     71.0
TEMPD    23     70.0
TEMP     24     24     71.0
TEMPD    24     70.0
TEMP     25     25     71.0
TEMPD    25     70.0
TEMP     26     26     71.0
TEMPD    26     70.0
TEMP     27     27     71.0
TEMPD    27     70.0
TEMP     28     28     71.0
TEMPD    28     70.0
TEMP     29     29     71.0
TEMPD    29     70.0
TEMP     30     30     71.0
TEMPD    30     70.0
TEMP     31     31     71.0
TEMPD    31     70.0
TEMP     32     32     71.0
TEMPD    32     70.0
TEMP     33     33     71.0
TEMPD    33     70.0
$
```

Figure 1. NASTRAN Control Deck to Generate [TRAS] for the Verification Plate Model (Concluded)

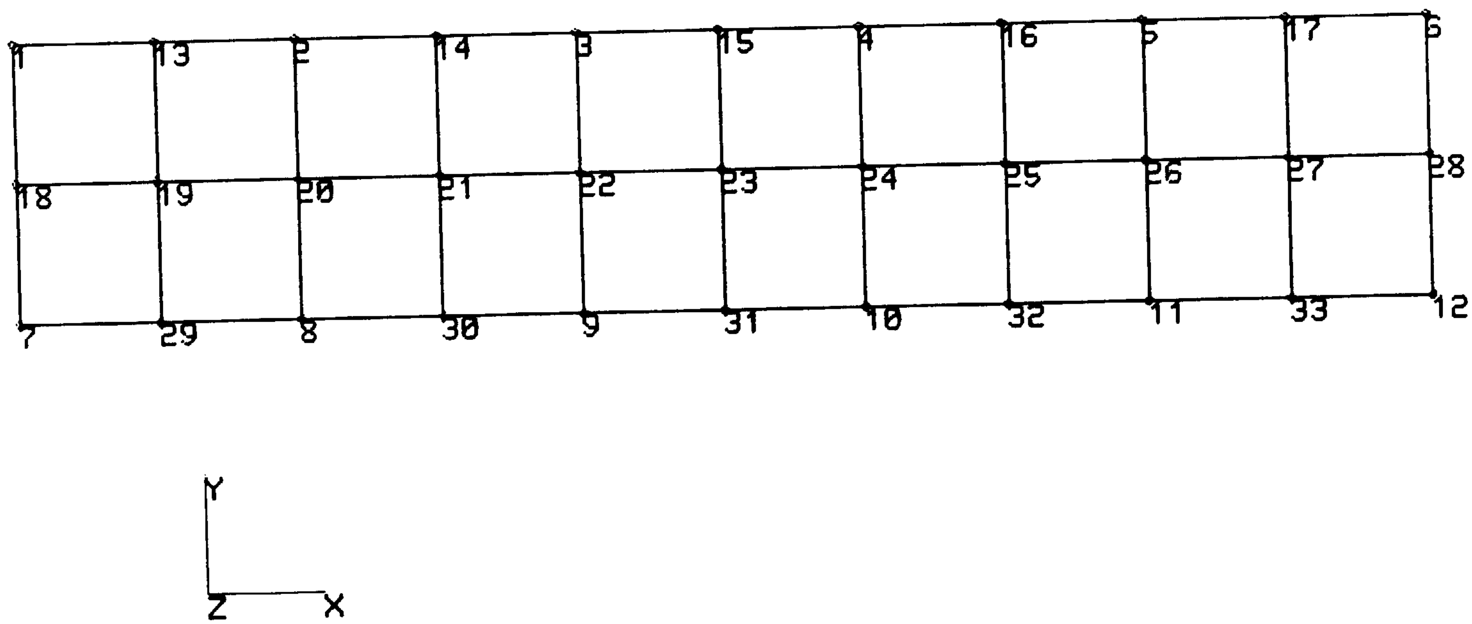

Figure 2. Plate Model Plot

```
$
SPC1     100      123456   1
$
TEMP     55       1        100.0
TEMP     55       2        300.0
TEMP     55       3        600.0
TEMP     55       4        600.0
TEMP     55       5        300.0
TEMP     55       6        100.0
TEMP     55       7        600.0
TEMP     55       8        300.0
TEMP     55       9        100.0
TEMP     55       10       100.0
TEMP     55       11       300.0
TEMP     55       12       600.0
TEMP     55       13       200.0
TEMP     55       14       450.0
TEMP     55       15       600.0
TEMP     55       16       450.0
TEMP     55       17       200.0
TEMP     55       18       350.0
TEMP     55       19       325.0
TEMP     55       20       300.0
TEMP     55       21       325.0
TEMP     55       22       350.0
TEMP     55       23       350.0
TEMP     55       24       350.0
TEMP     55       25       325.0
TEMP     55       26       300.0
TEMP     55       27       325.0
TEMP     55       28       350.0
TEMP     55       29       450.0
TEMP     55       30       200.0
TEMP     55       31       100.0
TEMP     55       32       200.0
TEMP     55       33       450.0
TEMPD    55       70.0
TEMPD    60       70.0
$
$                          ********** PLATE **********
$
$
GRID     1                 0.0      0.0      0.0
GRID     2                 50.0     0.0      0.0
GRID     3                 100.0    0.0      0.0
GRID     4                 150.0    0.0      0.0
GRID     5                 200.0    0.0      0.0
GRID     6                 250.0    0.0      0.0
GRID     7                 0.0      -50.     0.0
GRID     8                 50.0     -50.     0.0
GRID     9                 100.0    -50.     0.0
GRID     10                150.0    -50.     0.0
GRID     11                200.0    -50.     0.0
GRID     12                250.0    -50.     0.0
```

Figure 3. Plate Model Bulk Data

GRID	13		25.0	0.0	0.0			
GRID	14		75.0	0.0	0.0			
GRID	15		125.0	0.0	0.0			
GRID	16		175.0	0.0	0.0			
GRID	17		225.0	0.0	0.0			
GRID	18		0.0	-25.0	0.0			
GRID	19		25.0	-25.0	0.0		6	
GRID	20		50.0	-25.0	0.0		6	
GRID	21		75.0	-25.0	0.0		6	
GRID	22		100.0	-25.0	0.0		6	
GRID	23		125.0	-25.0	0.0		6	
GRID	24		150.0	-25.0	0.0		6	
GRID	25		175.0	-25.0	0.0		6	
GRID	26		200.0	-25.0	0.0		6	
GRID	27		225.0	-25.0	0.0		6	
GRID	28		250.0	-25.0	0.0			
GRID	29		25.0	-50.0	0.0			
GRID	30		75.0	-50.0	0.0			
GRID	31		125.0	-50.0	0.0			
GRID	32		175.0	-50.0	0.0			
GRID	33		225.0	-50.0	0.0			
CBAR	1	1	1	13	0.0	0.0	1.0	1
CBAR	2	1	13	2	0.0	0.0	1.0	1
CBAR	3	1	2	14	0.0	0.0	1.0	1
CBAR	4	1	14	3	0.0	0.0	1.0	1
CBAR	5	1	3	15	0.0	0.0	1.0	1
CBAR	6	1	15	4	0.0	0.0	1.0	1
CBAR	7	1	4	16	0.0	0.0	1.0	1
CBAR	8	1	16	5	0.0	0.0	1.0	1
CBAR	9	1	5	17	0.0	0.0	1.0	1
CBAR	10	1	17	6	0.0	0.0	1.0	1
CBAR	11	1	6	28	0.0	0.0	1.0	1
CBAR	12	1	28	12	0.0	0.0	1.0	1
CBAR	13	1	12	33	0.0	0.0	1.0	1
CBAR	14	1	33	11	0.0	0.0	1.0	1
CBAR	15	1	11	32	0.0	0.0	1.0	1
CBAR	16	1	32	10	0.0	0.0	1.0	1
CBAR	17	1	10	31	0.0	0.0	1.0	1
CBAR	18	1	31	9	0.0	0.0	1.0	1
CBAR	19	1	9	30	0.0	0.0	1.0	1
CBAR	20	1	30	8	0.0	0.0	1.0	1
CBAR	21	1	8	29	0.0	0.0	1.0	1
CBAR	22	1	29	7	0.0	0.0	1.0	1
CBAR	23	1	7	18	0.0	0.0	1.0	1
CBAR	24	1	18	1	0.0	0.0	1.0	1
$								
CQUAD4	1	1000	18	19	13	1		
CQUAD4	2	1000	19	20	2	13		
CQUAD4	3	1000	20	21	14	2		
CQUAD4	4	1000	21	22	3	14		
CQUAD4	5	1000	22	23	15	3		
CQUAD4	6	1000	23	24	4	15		
CQUAD4	7	1000	24	25	16	4		
CQUAD4	8	1000	25	26	5	16		
CQUAD4	9	1000	26	27	17	5		

Figure 3. Plate Model Bulk Data (Continued)

```
CQUAD4  10      1000    27      28      6       17
CQUAD4  11      1000    7       29      19      18
CQUAD4  12      1000    29      8       20      19
CQUAD4  13      1000    8       30      21      20
CQUAD4  14      1000    30      9       22      21
CQUAD4  15      1000    9       31      23      22
CQUAD4  16      1000    31      10      24      23
CQUAD4  17      1000    10      32      25      24
CQUAD4  18      1000    32      11      26      25
CQUAD4  19      1000    11      33      27      26
CQUAD4  20      1000    33      12      28      27
$
PSHELL  1000    4000    .7      4000            4000
$
PBAR    1       4000    1.9375  4.85    4.85    7.27
$
MAT1    4000    1.0+7           .33     .000371 13.3-6  70.0
$
ENDDATA
```

Figure 3. Plate Model Bulk Data (Concluded)

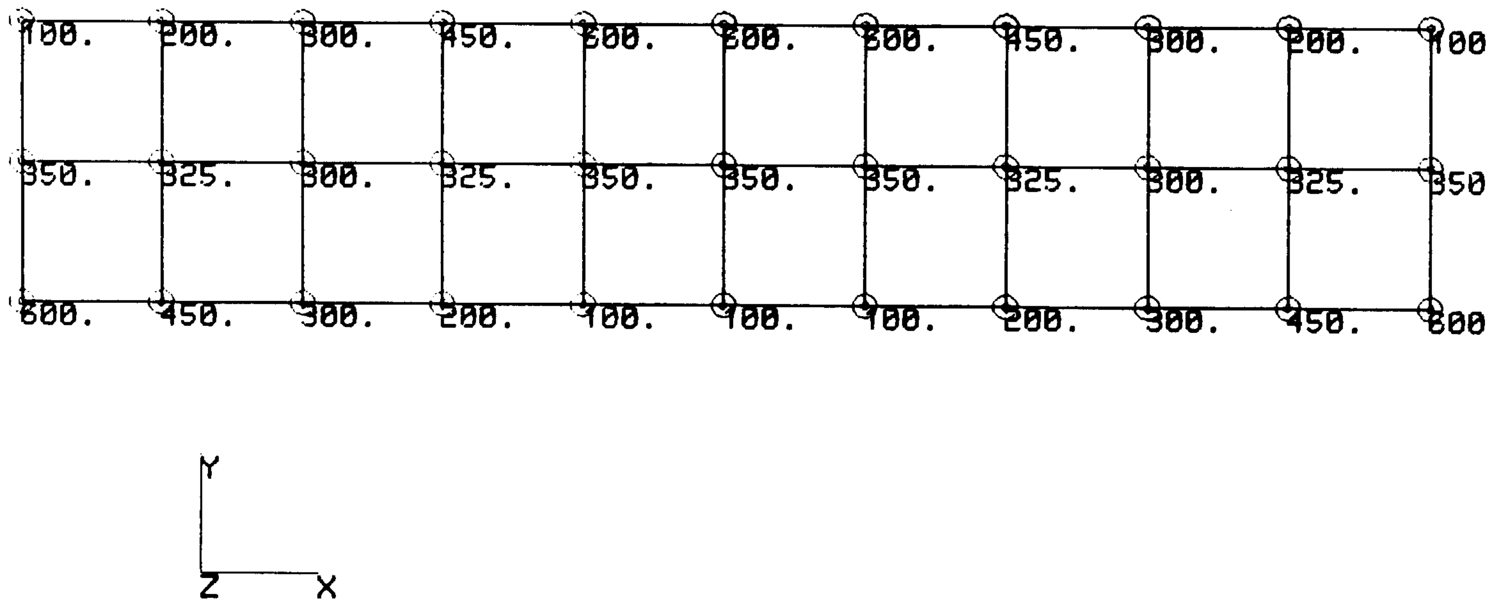

Figure 4. Temperatures Applied to the Plate Model

ANALYSIS OF PLATE MODEL
RUN TO GENERATE THERMAL STRESSES

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S T R E S S E S   I N   B A R   E L E M E N T S   (C B A R)

ELEMENT ID.	SA1 / SB1	SA2 / SB2	SA3 / SB3	SA4 / SB4	AXIAL STRESS	SA-MAX / SB-MAX	SA-MIN / SB-MIN	M.S.-T / M.S.-C
1	0.0	0.0	0.0	0.0	4.815285E+03	4.815285E+03	4.815285E+03	
	0.0	0.0	0.0	0.0		4.815285E+03	4.815285E+03	
2	0.0	0.0	0.0	0.0	1.158353E+03	1.158353E+03	1.158353E+03	
	0.0	0.0	0.0	0.0		1.158353E+03	1.158353E+03	

ANALYSIS OF PLATE MODEL
RUN TO GENERATE THERMAL STRESSES

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S T R E S S E S   I N   G E N E R A L   Q U A D R I L A T E R A L   E L E M E N T S   (C Q U A D 4)
(IN STRESS COORDINATE SYSTEM)

ELEMENT ID.	FIBRE DISTANCE	STRESSES IN STRESS COORD. SYSTEM NORMAL-X	NORMAL-Y	SHEAR-XY	PRINCIPAL STRESSES (ZERO SHEAR) ANGLE	MAJOR	MINOR	MAX SHEAR
1	-3.500000E-01	2.709319E+03	4.505912E+02	-6.043338E+01	-1.5315	2.710935E+03	4.489755E+02	1.130980E+03
	3.500000E-01	2.709319E+03	4.505912E+02	-6.043338E+01	-1.5315	2.710935E+03	4.489755E+02	1.130980E+03
2	-3.500000E-01	8.944683E+02	2.615569E+02	-1.671155E+02	-13.9189	9.358838E+02	2.201414E+02	3.578712E+02
	3.500000E-01	8.944683E+02	2.615569E+02	-1.671155E+02	-13.9189	9.358838E+02	2.201414E+02	3.578712E+02

Figure 5. Thermal Stresses from a Direct NASTRAN Solution of the Plate Model

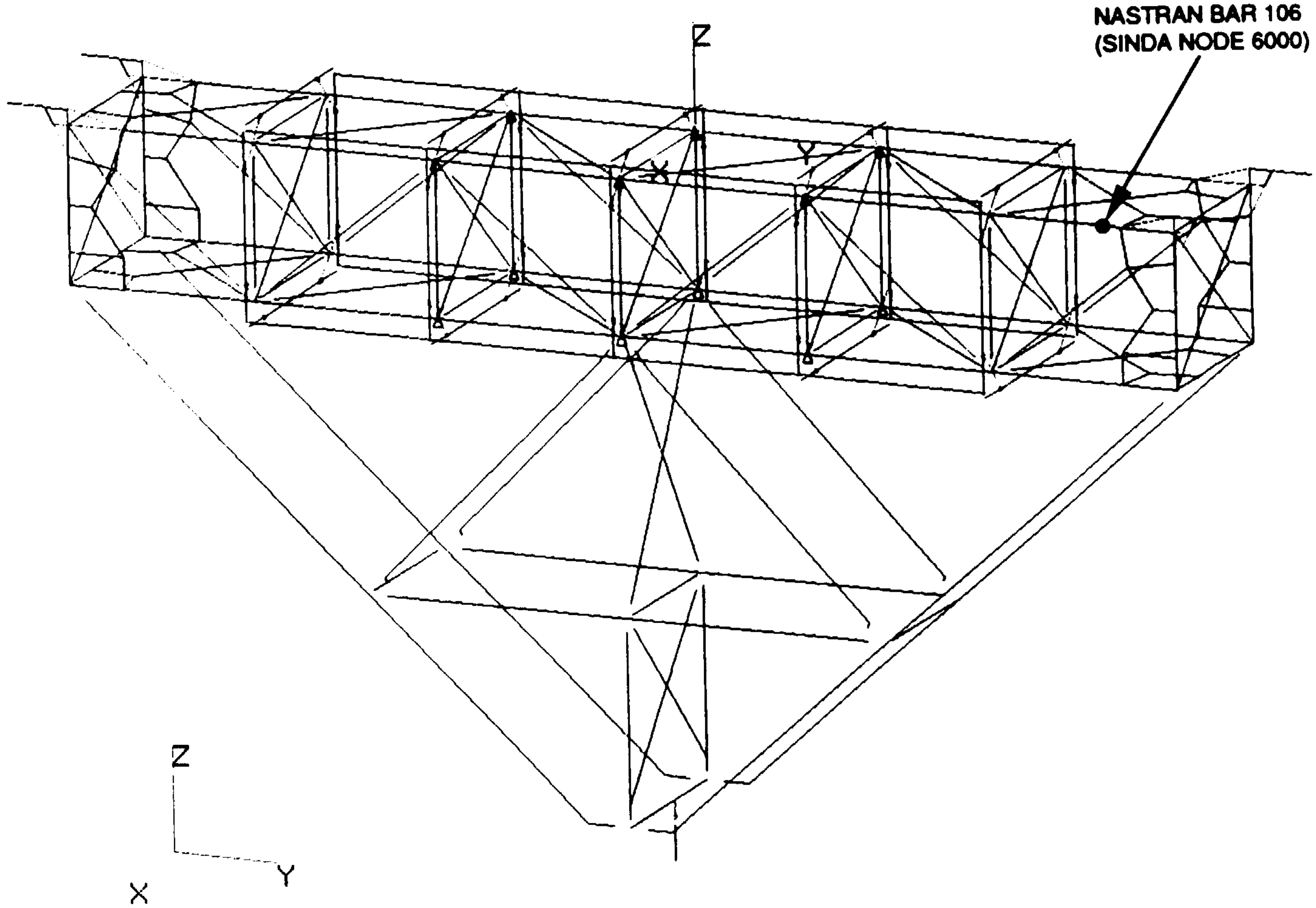

Figure 6. MPESS Finite Element Model

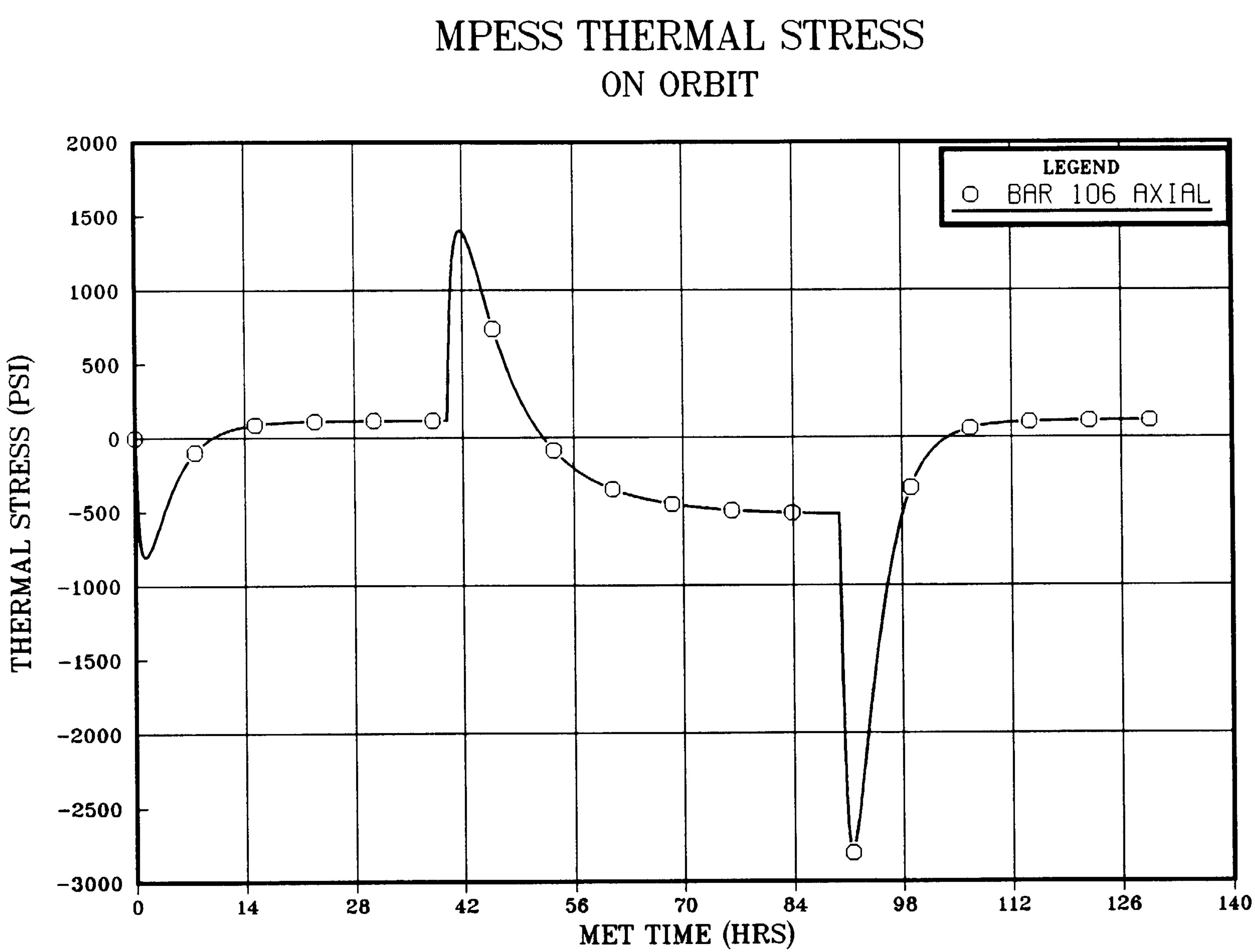

Figure 7. MPESS BAR 106 (SINDA Node 6000) Axial Stress Time History

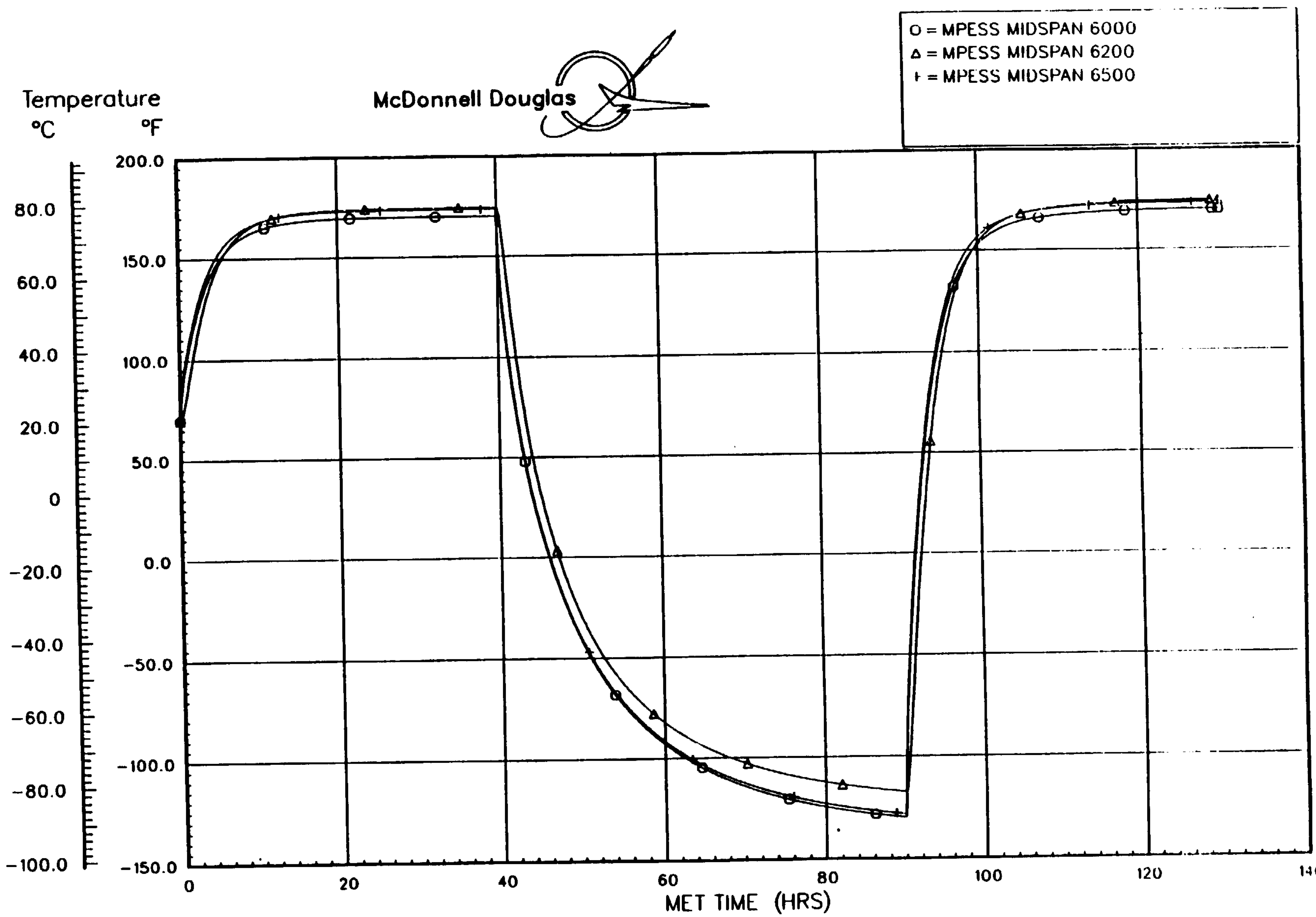

Figure 8. MPESS BAR 106 (SINDA Node 6000) Temperature Time History

TABLE 1. SPACELAB MULTI - PURPOSE EXPERIMENT SUPPORT STRUCTURE THERMAL STRESS MAX/MIN SUMMARY

ROW	DESCRIPTION	STRESS TYPE	EID	MAX	TIME	CASE	MIN	TIME	CASE
1	CBAR	SA1	106	799.737	92.500	ORBIT	-1574.153	89.950	ORBIT
2		SA2	106	616.297	41.000	ORBIT	-1087.696	91.000	ORBIT
3		SA3	106	1574.153	89.950	ORBIT	-799.737	92.500	ORBIT
4		SA4	106	1087.696	91.000	ORBIT	-616.297	41.000	ORBIT
5		AXIAL	106	1403.170	41.700	ORBIT	-2810.078	91.500	ORBIT
6		SB1	106	536.807	92.000	ORBIT	-815.012	89.950	ORBIT
7		SB2	106	417.387	41.000	ORBIT	-752.511	90.800	ORBIT
8		SB3	106	815.012	89.950	ORBIT	-536.807	92.000	ORBIT
9		SB4	106	752.511	90.800	ORBIT	-417.387	41.000	ORBIT
10	CBAR	SA1	107	280.820	93.700	ORBIT	-134.335	42.800	ORBIT
11		SA2	107	398.181	93.700	ORBIT	-271.673	43.700	ORBIT
12		SA3	107	134.335	42.800	ORBIT	-280.820	93.700	ORBIT
13		SA4	107	271.673	43.700	ORBIT	-398.181	93.700	ORBIT
14		AXIAL	107	1862.010	89.950	ORBIT	-1464.976	94.200	ORBIT
15		SB1	107	412.152	92.900	ORBIT	-379.209	89.950	ORBIT
16		SB2	107	598.601	91.100	ORBIT	-362.067	41.300	ORBIT
17		SB3	107	379.209	89.950	ORBIT	-412.152	92.900	ORBIT
18		SB4	107	362.067	41.300	ORBIT	-598.601	91.100	ORBIT
19	CBAR	SA1	108	1722.223	89.950	ORBIT	-900.599	0.020	DESCENTH
20		SA2	108	370.978	41.100	ORBIT	-395.292	91.500	ORBIT
21		SA3	108	900.599	0.020	DESCENTH	-1722.223	89.950	ORBIT
22		SA4	108	395.292	91.500	ORBIT	-370.978	41.100	ORBIT
23		AXIAL	108	1574.609	91.200	ORBIT	-1176.477	41.300	ORBIT
24		SB1	108	501.320	40.500	ORBIT	-1290.434	90.400	ORBIT
25		SB2	108	250.335	0.570	DESCENTC	-398.063	39.900	ORBIT
26		SB3	108	1290.434	90.400	ORBIT	-501.320	40.500	ORBIT
27		SB4	108	398.063	39.900	ORBIT	-250.335	0.570	DESCENTC

MDSSC - HUNTSVILLE OPERATIONS

TABLE 2. THERMAL STRESSES IN THE PLATE MODEL FROM THE TRANSIENT THERMAL STRESS RECOVERY PROCEDURE

ROW	ELEMENT TYPE	STRESS COMPONENT	EID	MAX	TIME	CASE	MIN	TIME	CASE
1	CBAR	SA1	1	0.000	0.000	N/A	0.000	0.000	N/A
2		SA2	1	0.000	0.000	N/A	0.000	0.000	N/A
3		SA3	1	0.000	0.000	N/A	0.000	0.000	N/A
4		SA4	1	0.000	0.000	N/A	0.000	0.000	N/A
6		AXIAL	1	4815.285	1.000	CASE1	4815.285	1.000	CASE1
7		SB1	1	0.000	0.000	N/A	0.000	0.000	N/A
8		SB2	1	0.000	0.000	N/A	0.000	0.000	N/A
19		SB3	1	0.000	0.000	N/A	0.000	0.000	N/A
10		SB4	1	0.000	0.000	N/A	0.000	0.000	N/A
11	CBAR	SA1	2	0.000	0.000	N/A	0.000	0.000	N/A
12		SA2	2	0.000	0.000	N/A	0.000	0.000	N/A
13		SA3	2	0.000	0.000	N/A	0.000	0.000	N/A
14		SA4	2	0.000	0.000	N/A	0.000	0.000	N/A
15		AXIAL	2	1158.353	1.000	CASE1	1158.353	1.000	CASE1
16		SB1	2	0.000	0.000	N/A	0.000	0.000	N/A
17		SB2	2	0.000	0.000	N/A	0.000	0.000	N/A
18		SB3	2	0.000	0.000	N/A	0.000	0.000	N/A
19		SB4	2	0.000	0.000	N/A	0.000	0.000	N/A
13	CQUAD4	NORMAL-X AT Z1	1	2709.319	1.000	CASE1	2709.319	1.000	CASE1
14		NORMAL-Y AT Z1	1	450.591	1.000	CASE1	450.591	1.000	CASE1
15		SHEAR-XY AT Z1	1	-60.433	1.000	CASE1	-60.433	1.000	CASE1
19		NORMAL-X AT Z2	1	2709.319	1.000	CASE1	2709.319	1.000	CASE1
20		NORMAL-Y AT Z2	1	450.591	1.000	CASE1	450.591	1.000	CASE1
21		SHEAR-XY AT Z2	1	-60.433	1.000	CASE1	-60.433	1.000	CASE1
22	CQUAD4	NORMAL-X AT Z1	2	894.468	1.000	CASE1	894.468	1.000	CASE1
23		NORMAL-Y AT Z1	2	261.557	1.000	CASE1	261.557	1.000	CASE1
24		SHEAR-XY AT Z1	2	-167.116	1.000	CASE1	-167.116	1.000	CASE1
25		NORMAL-X AT Z2	2	894.468	1.000	CASE1	894.468	1.000	CASE1
26		NORMAL-Y AT Z2	2	261.557	1.000	CASE1	261.557	1.000	CASE1
27		SHEAR-XY AT Z2	2	-167.116	1.000	CASE1	-167.116	1.000	CASE1

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