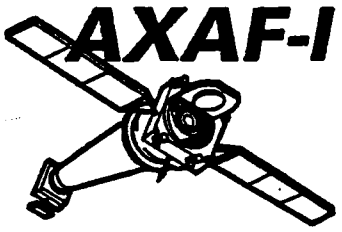
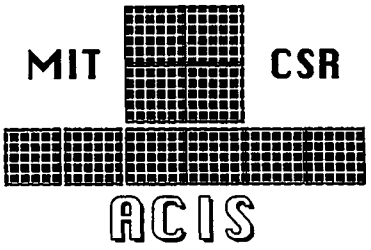
R. GOEKE

CSR

36-01505 Rev A
October 11, 1996
NAS8-37716
(Ref. MSFC SPEC-1836B)





Advanced X-ray
Astrophysics Facility

AXAF - I
CCD Imaging Spectrometer

SS Fracture and Fatigue Analysis

Submitted to:

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, AL 35812

Submitted by:

Center for Space Research
Massachusetts Institute of Technology
Cambridge, MA 02139

ACIS Revsion History Sheet

ECO	Rev.	Description	Checked	Approved	Date
36-774	A	Initial Release	MJF		10/25/96

1.0 INTRODUCTION

The following pages contain the fracture and fatigue analysis for the ACIS Support Structure (SS) Assembly.

2.0 FRACTURE CONTROL ANALYSIS

Fracture control analysis has been run, following the plan presented in MIT document 36-01213 Rev. A. The requirements specified in MSFC-HDBK-1453 were used to disposition the components into a fracture control category (see Appendix A), that is Low Mass, Contained, Fail-Safe, or Fracture Critical. Fracture Critical parts require a Safe Life Analysis. One such part was identified, this is the SS Mounting Flexure, drawing number 36-30106. A fatigue crack growth analysis was run using the NASA FLAGRO analysis program. This analysis showed that critical crack size would not be reached.

3.0 CALCULATION OF DESIGN LIMIT STRESS

The design limit stress was first determined and then used in setting up the load schedule for the safe life analysis. This stress was calculated using the COSMOS/M computer analysis program. The model used was referred to as the SS assembly model. The model was composed primarily of 4 node plate elements and beam elements, with some rigid bars and mass elements. The model, which is shown in Figure 1, has 1178 elements and 1281 nodes. After calculating the maximum stresses using the SS assembly model, as a check on the results, a much more detailed solid model of the flexure was constructed. This model, which was called the detailed flexure model was composed of 18344 tetra4 elements and had 4990 nodes. This model is shown in Figure 2. The model was assumed to be rigidly fixed at its interface with the Support Structure side wall. The reaction forces and moments, from the loading condition which yielded the maximum stresses cited above, were used to load the model. Analysis using this model calculated stresses that were several thousand psi less than those obtained with the SS assembly model. To be conservative, the higher stresses of the SS Assembly model were used in the Safe Life analysis.

The design limit stress for the flexure takes place during lift-off. It occurs on flexure #3, at the outer edge at a corner, where the flexure blade is joined to the mounting pad. This tension / compression stress results from both a direct stress and bending about the weak axis. The design limit stress is equal to +/- 33540 psi.

4.0 LOAD SCHEDULE FOR THE SS SAFE LOAD ANALYSIS

In setting up the load schedule, the stresses due to lift-off and landing are multiplied by the number of cycles specified in the STS Payload Launch and Landing Fatigue Spectra that is presented on page 41 of SE11i (see Attachment 1). Two launches and one landing are assumed. These components of the schedule, and all others are then multiplied by a scatter factor of four (four lifetimes). The methodology behind the calculation of the numbers of cycles of loading due to other sources, e.g. sinusoidal, random vibration and acoustic testing and transportation, is presented in Attachment 2. This attachment was generated by MITs' subcontractor Lockheed Martin. It has been used by them in building the fatigue load schedules for other successful Shuttle launched

space programs.

In building the fatigue load schedule, the SS assembly model was used to determine the maximum flexure stresses for 1G loads in the X, Y and Z directions. These results are shown in Appendix B. The appropriate G loadings were then used as multipliers in calculating the maximum stresses for the varying loading conditions. These stresses were calculated in the most conservative way possible. The absolute values of the maximum stresses due to X, Y and Z loadings were added together. As a further conservatism, the stresses were combined without regard to their location on the flexure, or on which flexure the stress occurred.

Appendix C shows the calculation of the design limit stresses for both the sinusoidal testing and the abort landing loading cases. Appendix D contains the design limit stress calculations for random vibration and acoustic testing, ground and air transportation, and launch and landing loads. Appendix E combines all these components together to form the fracture load spectra for the SS flexure. Table 1 below shows the load spectra thus formed.

Table 1: ACIS SS Flexure, Fracture Load Spectra

Percent of Design Limit Stress (33540 psi)	Stress (psi)	Cycles
100	33540	8
90	30186	1272
80	26832	1544
70	23478	3388
60	20124	7617
50	16770	17982
40	13416	33661
30	10062	908821
20	6708	194643
10	3354	1865451
	Total Cycles	3,034,387

5.0 SAFE LIFE ANALYSIS

The output from the FLAGRO analysis is given in Appendix F. The results show that critical

crack size was not reached.

6.0 FATIGUE ANALYSIS

The fatigue analysis was based on the loading schedule shown in Table 1. Table 2 is related to the loading schedule constructed for the safe life analysis, however the stresses were increased by a factor of 1.15 per MSFC-HDBK-505A. This means that the limit stress used for the fatigue life calculation is:

$$+/- 33540 \times 1.15 = +/- 38571 \text{ psi}$$

Table 2: ACIS SS Flexure, Fatigue Loads

Percent of Design Limit Stress (psi)	Stress (psi)	Cycles
100	38571	8
90	34714	1272
80	30856	1544
70	27000	3388
60	23143	7617
50	19286	17982
40	15428	33661
30	11571	908821
20	7714	194643
10	3857	1865451
	Total Cycles	3,034,387

To calculate the fatigue strength of the flexure, one would normally determine Miners' fatigue cycle ratio, using the data in Table 2 and the *S-N* curve for Ti-6Al-4V. *S-N* curves for metals are constructed on log/ log graph paper, with the stress level on the ordinate and the number of cycles on the abscissa. For steel or titanium alloys, the curve can be plotted as a straight line from a point at the ultimate allowable stress level (Ftu) and 1000 cycles to a point at 0.5 Ftu and 1.0E+6 cycles. This point is defined as the endurance limit. From this point the S-N curve is horizontal. The endurance limit is defined as the highest alternating stress value that a structural element can withstand, without failure, regardless of the number of applied loading cycles. The endurance limit for aluminum alloys is about 0.33 Ftu. To be conservative, we will use this lower estimate of the

endurance limit for titanium.

$$0.33\ F(tu) = 0.33\ (130{,}000) = 42{,}900\ \text{psi}.$$

It can be seen that all of the stresses in Table 2 are less than the endurance limit, and therefore no fatigue problem exists.

Attachment 1

Table 8.0-1 STS Payload Launch and Landing Fatigue Spectra (From References 18 and 19)

Load Step No.	Cycles/Flight		Cyclic Stress (% Limit Value)	
	Launch	Landing	Minimum	Maximum
1	1	1	- 100	100
2	3	1	- 90	90
3	5	3	- 80	80
4	12	3	- 70	70
5	46	3	- 60	60
6	78	3	- 50	50
7	165	13	- 40	40
8	493	148	- 30	30
9	2229	891	- 20	20
10	2132	1273	- 10	10
11	2920	2099	- 7	7
12	22272	6581	- 5	5
13	82954	8701	-3	3

Attachment 2
Methodology for Calculating Load Cycles

Note:
This analysis was provided by Lockheed Martin Astronautics, Inc., Denver, which is a major contractor to MIT on the ACIS/AXAF project. This methodology has been used by LMA on other programs which use the Shuttle as a launch vehicle.

3.1 Testing

Sinusoidal sweep testing

Some TSS hardware components are subjected to sinusoidal sweep testing. The additional cycles due to this testing must be included in the fracture analysis.

The cycles for sine sweeps will be calculated as follows:

a) Wide band response will be assumed since a typical component will have several resonances in the sweep frequency range;
b) The frequency range of interest is from 35 Hz (or fundamental frequency of the component if < 35 Hz) to 500 Hz (or the upper sweep frequency if <500 Hz);
c) The peak response of the component is known and is assumed to be fully reversible;
d) The number of equivalent cycles at the maximum stress level for one sweep can be determined from

$$N_{eq} = \frac{60}{\lambda(\ln 2)} \Delta f$$

where N_{eq} = Number of equivalent cycles at σ_{max}

λ = Sweep rate (octaves/min)

Δf = Frequency range of system.

If a sine sweep test includes a sweep up and a sweep down, N_{eq} must be doubled.

For example if a particular component has been tested at 0.5 g's from 5 to 2000 Hz at a sweep rate of 1 octave/minute, the number of cycles is

$$N_{eq} = \frac{60}{1(\ln 2)} (500 - 35) = 40251 \text{ cycles at } \sigma_{max}$$

A scatter factor of 4 must be applied to account for the safe-life requirement, giving a total number of 161,004 cycles per sweep.

Random vibration testing

The cycles for random vibration testing are given in Table 3-1. These cycles were calculated as follows:

a) Total number of cycles = fundamental frequency of part multiplied by the time duration of the test;

b) The probability of attaining a given peak stress level is derived from a Rayleigh distribution;

c) Peak stress level is given by the 3σ stress level derived from the random vibration criteria for the part.

All values in Table 3-1 are based on a frequency of 100 Hz. The number of cycles in Table 3-1 should be modified based on the fundamental frequency of the part being analyzed. For instance, if the part being analyzed has a fundamental frequency of 36 Hz, the cycles in Table 3-1 would be multiplied by (36/100) or 0.36.

The JQUAT random vibration tests are run for 60 seconds in each axis. A scatter factor of four must be applied to the random vibration test cycles. The last two columns in Table 3-1 provide the number of cycles due to a 60 second test duration, both with and without the scatter factor.

Table 3-1: Fracture Cycles for Random Vibration Environment

Percent of Limit Load	Percent of Total Cycles	Number of Cycles for 60 Seconds (f_n = 100 Hz)	Number of Cycles with Scatter Factor
0 - 10	4.40	264	1056
10 - 20	12.07	724	2896
20 - 30	16.83	1010	4040
30 - 40	18.02	1081	4324
40 - 50	16.37	982	3928
50 - 60	12.84	770	3080
60 - 70	8.95	537	2148
70 - 80	5.75	345	1380
80 - 90	3.06	184	736
90 - 100	1.71	103	412
	Total Cycles	6000	24000

NOTE: Number of cycles are based on fundamental frequency of 100 Hz. For a different fundamental frequency multiply cycles by fn/100.

Static testing

If a component has undergone static proof testing the cycles due the the testing must be included in the fracture and fatigue analysis. The cycle count is determined as one cycle at the maximum applied load for each load application multiplied by the the scatter factor of 4. For example, if a component is tested with one load case where 100 lbs are

applied in the X axis and one load case where 200 lbs are applied in the Y axis, the cycles for the fracture/fatigue analysis are

1 cycle @ 100 lbs * 4 (scatter factor) = 4 cycles @ 100 lbs
1 cycle @ 200 lbs * 4 (scatter factor) = 4 cycles @ 200 lbs

Acoustic testing

The acoustic test on the TSS-1 Deployer will have a 60 second duration at the JQUAT overall sound pressure level of 139 dB. Cycles for the acoustic test are computed in the same manner as the random vibration testing. See Table 3-1 for cycles.

The peak stress used with the acoustic test cycles is determined from the JQUAT random vibration criteria just as it was for the random vibration testing. Since the acoustic test is not conducted one axis at a time use the highest 3σ peak stress calculated for the random vibration testing and the cycles associated with that stress.

3.2 Ground and flight operations

Ground and flight operations will occur once for each mission. Components must withstand 4 life-times per mission. Cycles given in the following paragraphs are for one life-time.

Transportation

The transportation cycles provided here are based on transportation data gathered on a classified program at MMAG. Data was collected for both ground and air transportation. An analysis was performed to determine the best way to characterize the fracture cycle spectra based on the measured data.

For ground transportation the following assumptions were used:

a) one 3σ event occurs every 200 miles of travel;
b) a Gaussian distribution was used to determine the number of events at each increment of limit load based on one 3σ event;
c) the events were unforced vibrations and logarithmic decrements were used to determine the number of cycles per event at each load increment;
d) the number of events at each load increment multiplied by the cycles/event at each load increment gives the total number of cycles for each load increment;
e) a structural damping value of 1% of critical was used in the log decrement calculations.

Table 3.1.2.1.1-1 Design Limit Load Factors for GSE and Test Fixtures

Medium/Mode	Load Factors (Gs)			Load	Safety Factor	
	Fore/Aft	Lateral	Vertical**	Apply	Yield	Ultimate
Water Barge/Dock Bumping	+0.5 -0.5	+1.0 -1.0	+2.5 -0.5	S	2	3
Water Barge in Transient*	±0.09 ±0.00025h	±0.05 ±0.0013h	±1.0 ±0.0025x ±0.0013L	S	2	3
Air C5A	+3.0 -3.0	+1.5 -1.5	+3.0 -1.0	S	2	3
Truck Trailer	+2.0 -2.0	+2.0 -2.0	+3.5 -1.5	I	2	3
Truck Trailer, Air-Ride	+2.0 -2.0	+2.0 -2.0	+3.5 -1.5	I	2	3
Rail, Slow Moving No hump < 5 MPH	+1.0 -1.0	+0.75 -0.75	+1.5 -0.0	I	2	3
Dolly, Slow Moving 30 ft/min. Max.	+1.0 -1.0	+0.75 -0.75	+1.5 -0.0	I	2	3
Hoisting, Handling Erecting, Lowering			+1.0 -1.0	D	3	5
Fork-Lifing, Fork-Lowering	+1.0 -1.0	+0.5 -0.5	+2.0 -0.0	S	2	3
Seismic	+0.5 -0.5	+0.5 -0.5	+1.0 -1.5	S	2	3

*Distance in inches where:
L = Horizontal distance between center-line of barge roll to GSE cg
h = Vertical distance between center-line of barge roll to GSE cg
x = Axial distance between barge center-of-pitch to GSE cg

**Loads include the effect of gravity

S = Loads occur simultaneously in the three directions
I = Loads occur independently in the three directions except for gravity
D = Load in direction of travel

Note: The vertical direction "+" sign is directed toward the center of the earth

NOTE: FACTORS ON PREVIOUS PAGE WERE USED.

Table 3-2: Load Factors for Ground and Air Transportation

	Longitudinal	Lateral	Vertical
Ground Transportation (55/20 MPH)	± 0.7	± 1.7	± 3.2
Air Transpertation	± 0.9	± 0.8	± 0.7

Table 3-3: Truck Transportation Cycles Per 200 Miles of Travel

Percent of Limit Load	Percent of Total Events	Number of Events	Number of Cycles/Event	Number of Cycles
0 - 10	23.58	54.8	20.0	1096
10 - 20	21.57	50.2	11.0	552
20 - 30	18.04	42.0	6.5	273
30 - 40	13.79	32.1	4.6	148
40 - 50	9.66	22.5	3.6	81
50 - 60	6.17	14.3	2.9	41
60 - 70	3.61	8.4	2.5	21
70 - 80	1.94	4.5	2.1	10
80 - 90	0.72	1.7	1.9	3
90 -100	0.43	1.0	1.7	2

Table 3-4: Plane Transportation Cycles

Percent of Limit Load	Number of Cycles for Flight gusts	Number of Cycles for Landing	Total Cycles
0 - 10	1096	20	1116
10 - 20	552	11	563
20 - 30	273	6	279
30 - 40	148	5	153
40 - 50	81	4	85
50 - 60	41	3	44
60 - 70	21	2	23
70 - 80	10	2	12
80 - 90	3	2	5
90 -100	2	2	4

For air transportation, the following was used to match the measured data:

a) one 3σ flight gust per flight, cycles are counted the same way as for ground transportation;
b) landing can be represented as one 3σ event that decays to zero.

Load factors for ground and air transportation are given in Table 3-2. The worst combination of the load factors in Table 3-2 gives the peak stress to use with the transportation cycles. Figure 3-1 provides axis definition for the load factors.

Fracture cycles for ground transportation are given in Table 3-3. These cycles are for 200 miles of travel and must be multiplied by the ratio of (actual miles traveled)/(200 miles). Fracture cycles for air transportation are give in Table 3-4.

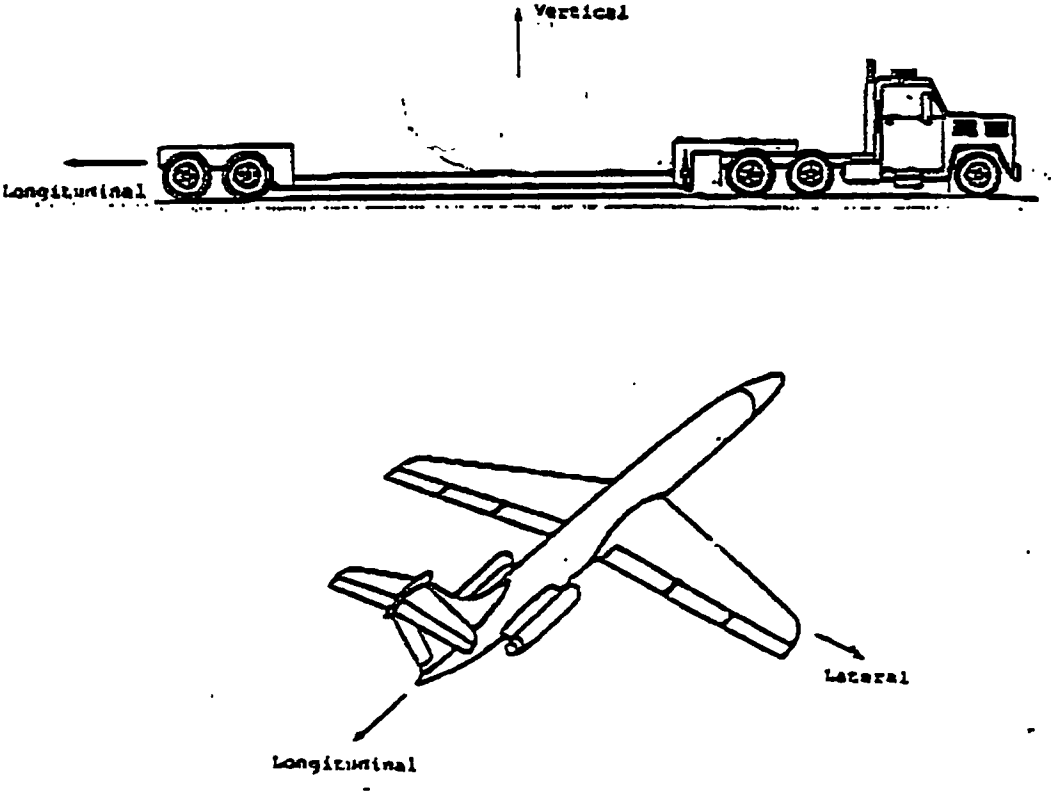


Figure 3-1: Transportation Load Factor Axis Definition

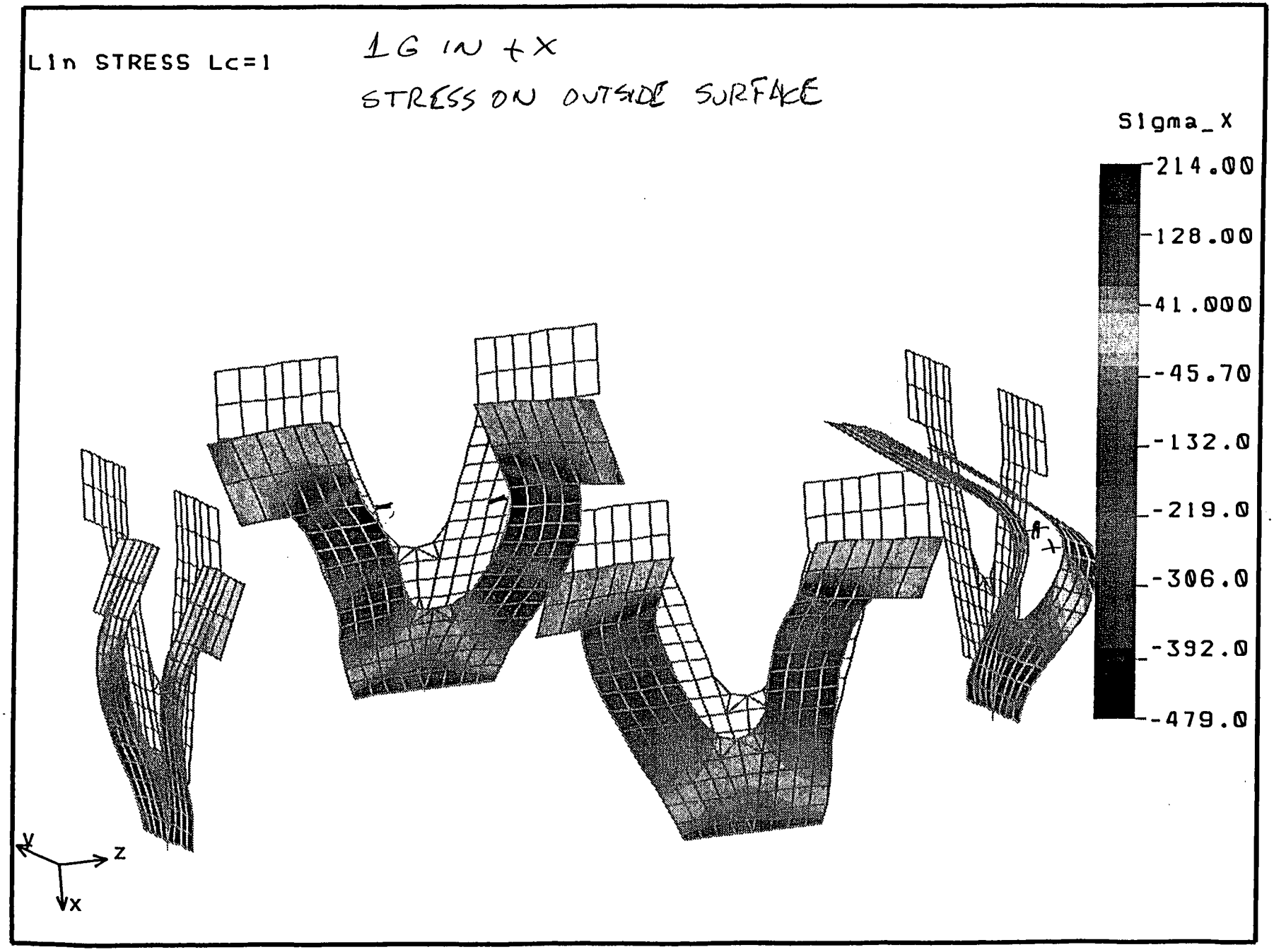
Appendix A

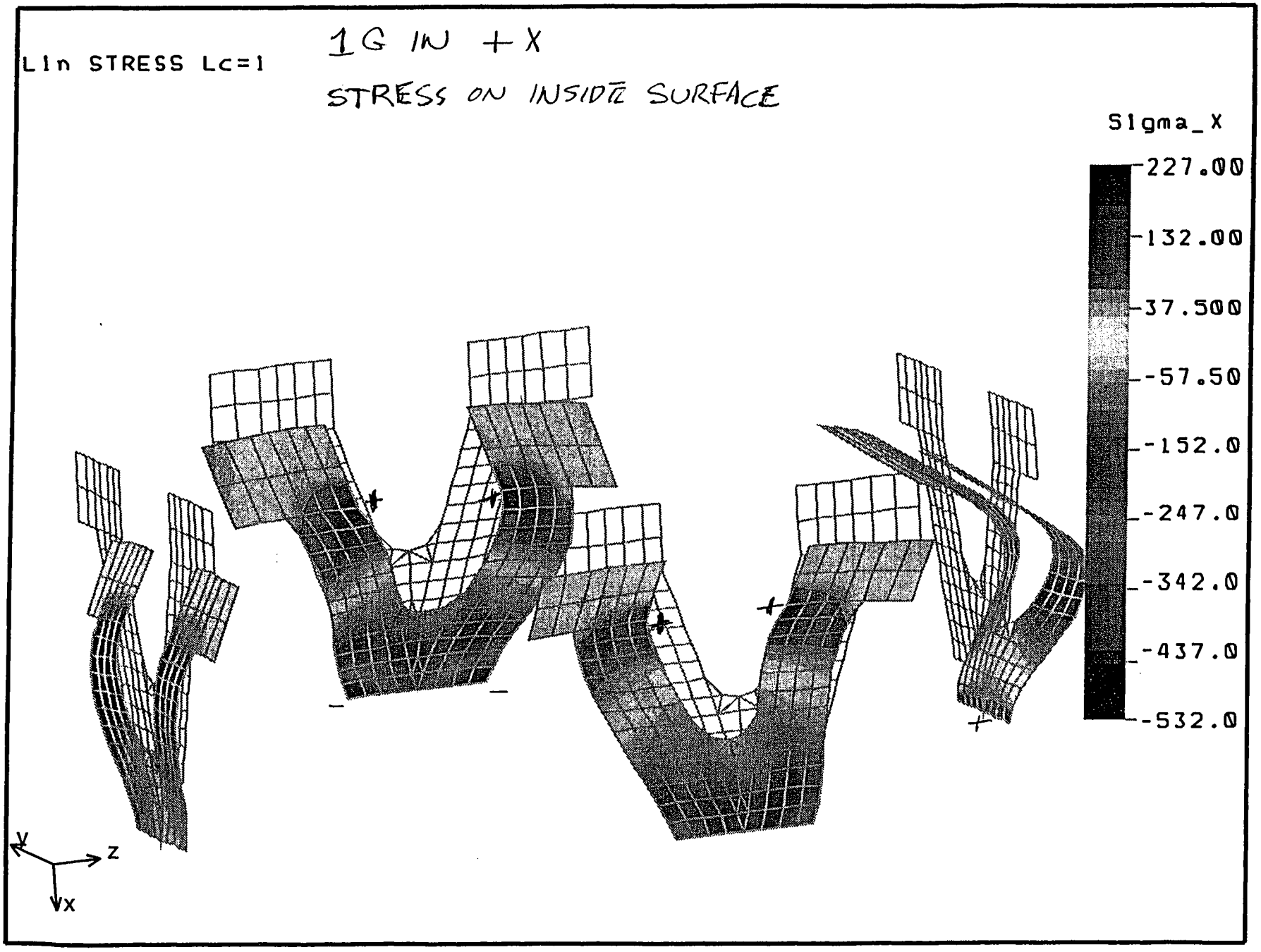
Fracture Control Analyses Summary			September 27, 1996			P. C. Tappan	
/amd/snebulos/h2/pct/acis/fracture.xs3							
Number	Quanity	Description	Low Mass	Contained/	Fail-Safe	Damage-	Safe-Life
36-				Restrained		Tolerant	
30000	1	SUPPORT ASSEMBLY, FLIGHT			X		
30100	1	Support Structure			X		
30101	1	..Support Structure, -X			X		
30102	1	..Support Structure, +Y			X		
30103	1	..Support Structure, -Y			X		
30104	1	..Support Structure +Z, Flexure Section			X		
30105	1	..Support Structure, -Z			X		
30106	4	..Mounting Flexure					X
30107	8	..Dowel Pin	X				
30108	2	..Support Bracket, Upper +Y and -Y Sides	X				
30109	1	..Support Bracket, Upper +Y Side	X				
30111	1	..Support Structure +Z, Cutout Section			X		
30112	1	..Support Bracket, Upper -Y Side	X				
30113	1	..Support Bracket, Lower +Y Side	X				
30114	1	..Support Bracket, Lower -Y Side	X				
30115	1	..Support Bracket, Lower +Y Side	X				
30116	1	..Support Bracket, Lower -Y Side	X				
30120	1	..Support Structure Heater Conn. Bracket	X				
30121	1	..Support Structure Thermistor Conn. Bracket	X				
30122	1	..Cable Assy, Support Structure, Survival Heaters		X			
30123	1	..Cable Assy Support Structure, Thermistor		X			
30128	A/R	..Epoxy Adhesive	X				
30129	A/R	..Tape, Aluminized, 3 mils	X				
30200	1	Detector Electronics Assembly			X		
30201	10	..Video CCA		X			
30202	1	..CCA - Interface/Thermal Control A		X			
30203	1	..DEA Backplane Assy		X			
30204	1	..Cable Assy-DEA Internal, Power 1		X			
30205	1	..Cable Assy-DEA Internal, Power 2		X			
30206	1	..Cable Assy-DEA Internal, Control 1		X			
30207	1	..Cable Assy-DEA Internal, Digital Data 1		X			
30208	1	..Cable Assy-DEA Internal, Digital Data 2		X			
30209	1	..Cable Assy-DEA Internal, High Speed Data		X			
30210	1	..DEA Housing Assembly			X		
30211	10	..Cable Clamp	X				
30212		..Tie Mount	X				
30213		..Filter Panel	X				
30215	1	..Cable Assy-DEA Internal, Control 2		X			
30217	1	..Bracket, Support	X				
30218	1	..Cover, Connector	X				
30219	1	..Cover, Rear Connector	X				
30220	A/R	..EMI Gasket	X				
30224	48	..Washer, #4 Reduced	X				
30225	24	..Nut, #4-40	X				
30226	232	..Screw, 6-32 UNC x .440L, SHC	X				
30227	232	..Washer, #6 Reduced	X				
30228	40	..Screw, #4-40 UNC x .500L, SHC	X				
30229	1	..Cable Assy, Thermistor		X			
30230	13	..Cable Mount, Tefzal	X				
30231	5	..Cable Blocks	X				

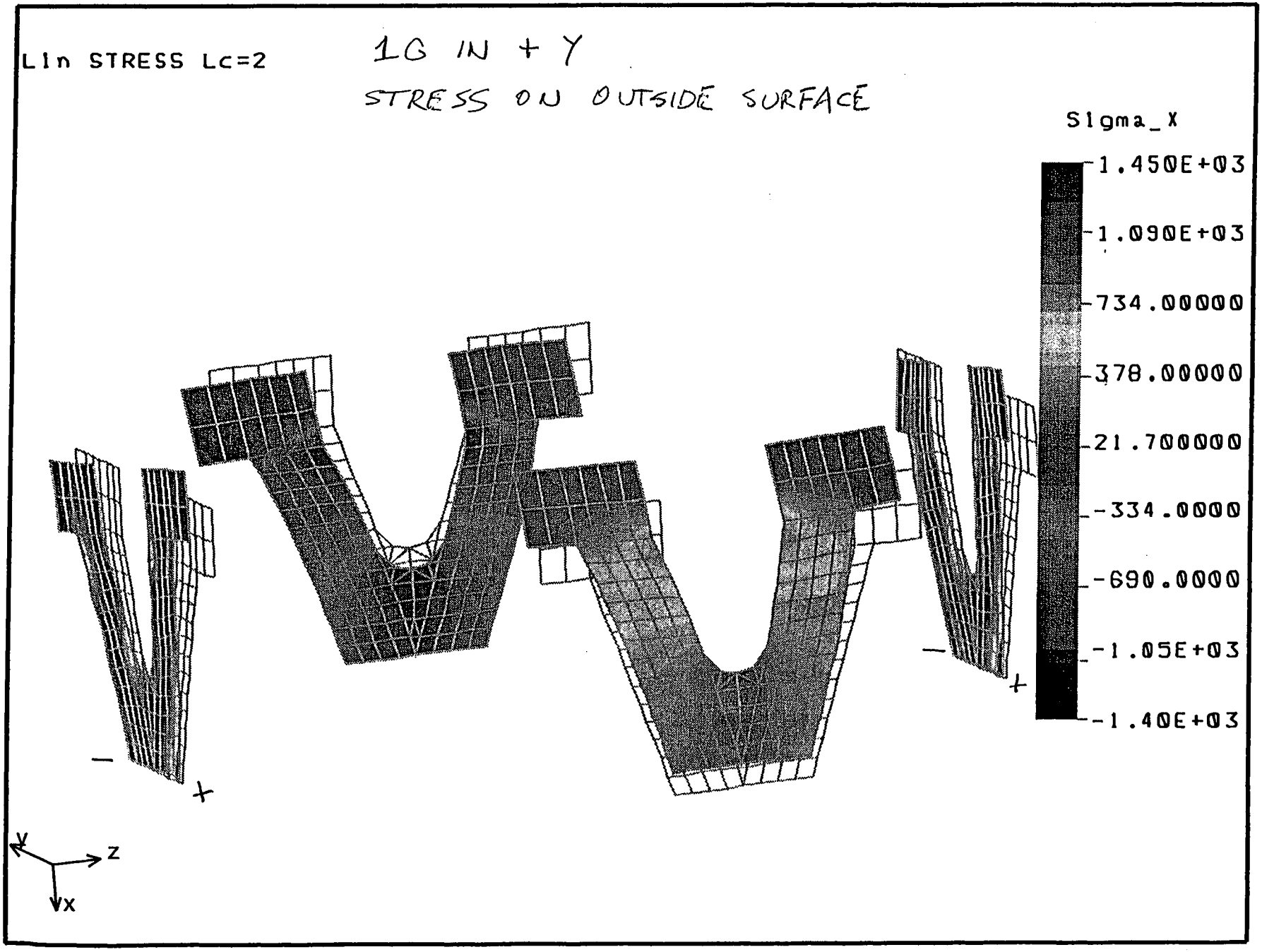
30232	A/R	..Caterpillar Grommet	X				
30233	A/R	..Tie Wraps, Tefzal	X				
30234	A/R	..Conformal Coat	X				
30235	A/R	..Paint (Black)	X				
30236	A/R	..Paint (White)	X				
30237	13	..Press-Fit Inserts	X				
30238	5	..Spacer, Cable Mount	X				
30241	A/R	..Epoxy	X				
30242	A/R	..Spotbond, Components	X				
30243	A/R	..Spotbond, Hardware	X				
30244	2	..Connector Gasket, 13	X				
30245	2	..Connector Gasket, 17	X				
30246	2	..Connector Gasket, 23	X				
30262	1	..CCA - Interface/Thermal Control B		X			
30263	1	..Shield, Inner, -X, DEA		X			
30264	1	..Shield, Outer, -X, DEA			X		
30265	1	..Shield, +Z, DEA			X		
30300	1	Digital Processing Assembly			X		
30301	2	..CCA-Back End Processor		X			
30302	6	..CCA-Front End Processor		X			
30303	1	..CCA Processor Preparatory		X			
30304	1	..DPA Backplane Assy		X			
30305	1	..Cable Assy-DPA Internal, Power & Sync A		X			
30306	1	..Cable Assy-DPA Internal, Power & Sync B		X			
30307	1	..Cable Assy-DPA Internal, Digital Data 1		X			
30308	1	..Cable Assy-DPA Internal, Digital Data 2		X			
30309	1	..Cable Assy-DPA Internal, Control 1		X			
30310	1	..DPA Housing Assembly			X		
30311	10	..Cable Clamp	X				
30312		..Tie Mount	X				
30313		..Vent Panel	X				
30315	1	..Cable Assy-DPA Internal, RCTU A		X			
30316	1	..Cable Assy-DPA Internal, RCTU B		X			
30317	1	..CCA-Power Distribution		X			
30318	1	..Cable Assy-DPA Internal, DPA Power		X			
30319	A/R	..EMI Gasket	X				
30320	1	..Bracket, Support	X				
30321	1	..Cover, Connector	X				
30323	24	..Screw, 4-40 UNC x .620L, SHC	X				
30324	52	..Washer, #4 Reduced	X				
30325	24	..Nut, #4-40	X				
30326	232	..Screw, 6-32 UNC x .440L, SHC	X				
30327	232	..Washer, #6 Reduced	X				
30328	28	..Screw, 4-40 UNC x .500L, SHC	X				
30329	1	..Cable Assy-DPA Internal, Control 2		X			
30334	1	..Cable Assy-DPA Internal, Thermistor		X			
30335	2	..Thermistor, 2.2K at 25 deg.C	X				
30336	2	..Resistor, 5.23K, 1/4W, 1%	X				
30337	2	..Bondable Terminal	X				
30338	2	..Connector Gasket, 17	X				
30339	2	..Connector Gasket, 13	X				
30340	2	..Connector Gasket, 23	X				
30341	2	..Connector Gasket, 15	X				
30342	A/R	..Epoxy	X				
30343	A/R	..Solder, 63/37	X				
30344	A/R	..Spotbond, Components	X				

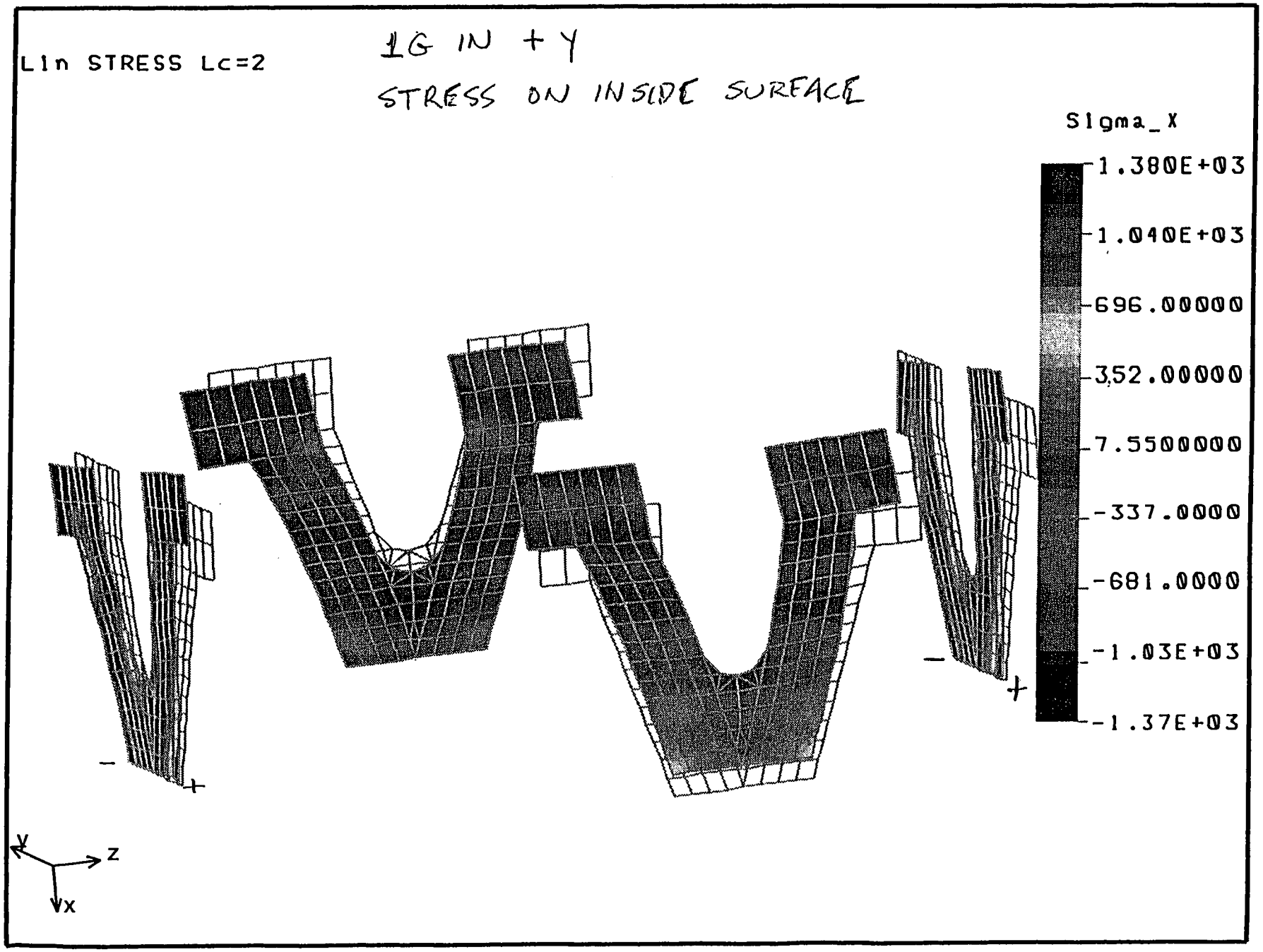
30345	A/R	..Spotbond, Hardware	X				
30346	1	..Panel Stiffener		X			
30347	25	..Cable Mount, Tefzal	X				
30348	4	..Screw, Flat Head, CRS, 8-32 x 0.31	X				
30349	A/R	..Caterpillar Grommet	X				
30350	A/R	..Tie Wrap, Tefzal	X				
30351	A/R	..Conformal Coat	X				
30352	A/R	..Paint (Black)	X				
30353	A/R	..Paint (White)	X				
30354	20	..Spacer, Cable Mount	X				
30400	1	Support Structure Cable Set		X			
30402	1	..Cable Assy-Support Structure, Control 1		X			
30403	1	..Cable Assy-Support Structure, Digital Data 1		X			
30404	1	..Cable Assy-Heater Control		X			
30405	1	..Cable Assy-CCD Interface I0		X			
30406	1	..Cable Assy-CCD Interface I2		X			
30407	1	..Cable Assy - CCD Interface I1		X			
30408	1	..Cable Assy - CCD Interface I3		X			
30409	1	..Cable Assy - CCD Interface S0		X			
30410	1	..Cable Assy - CCD Interface S1		X			
30411	1	..Cable Assy - CCD Interface S2		X			
30412	1	..Cable Assy - CCD Interface S3		X			
30413	1	..Cable Assy - CCD Interface S4		X			
30414	1	..Cable Assy - CCD Interface S5		X			
30415	1	..Cable Assy-Support Structure, Digital Data 2		X			
30416	1	..Cable Assy-Support Structure, Control 2		X			
30418	1	..DEA Bulkhead Cable Feethru	X				
30420	1	..S0-S5 Cable Bracket			X		
30421	1	..I2,I3 Cable Bracket			X		

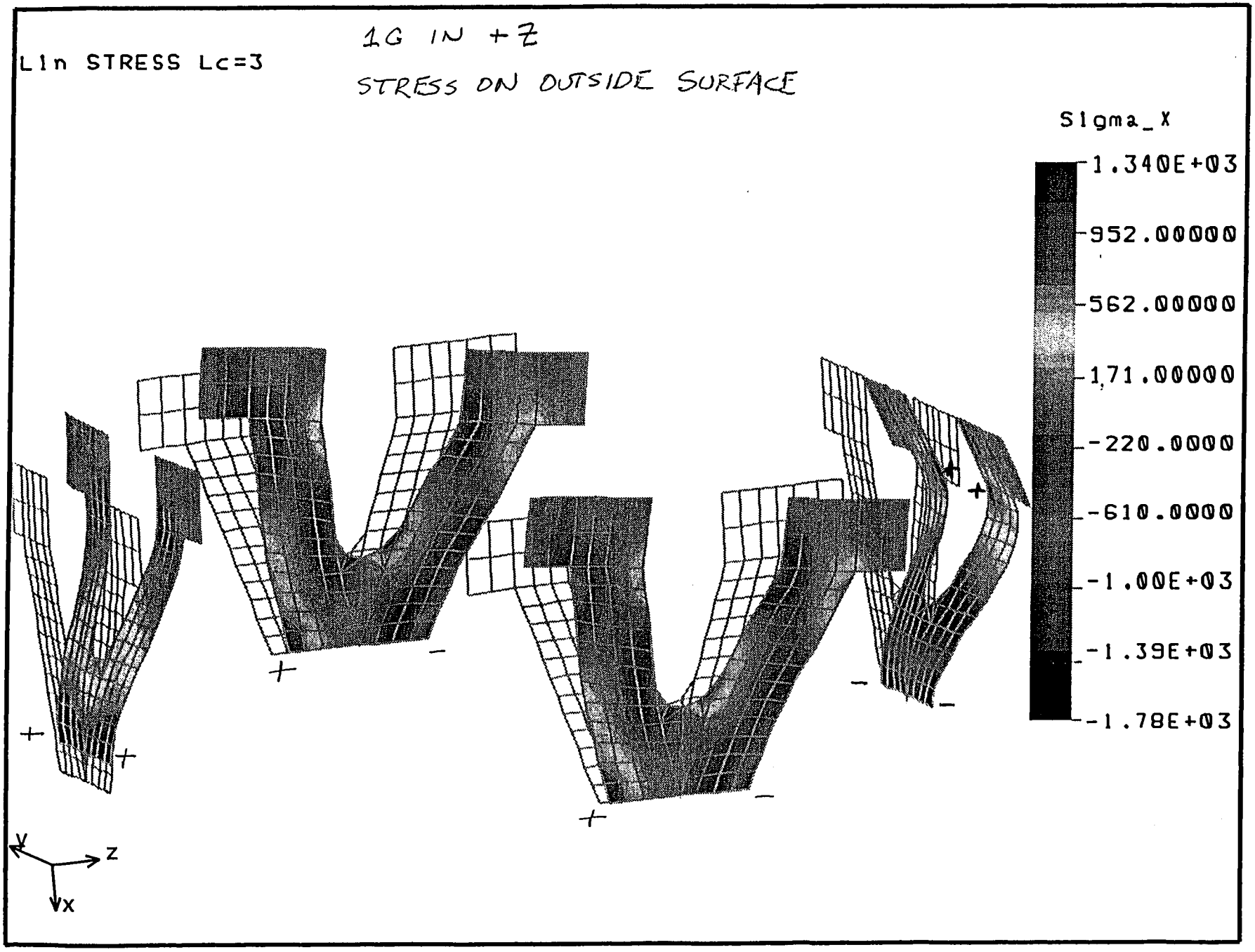
Appendix B

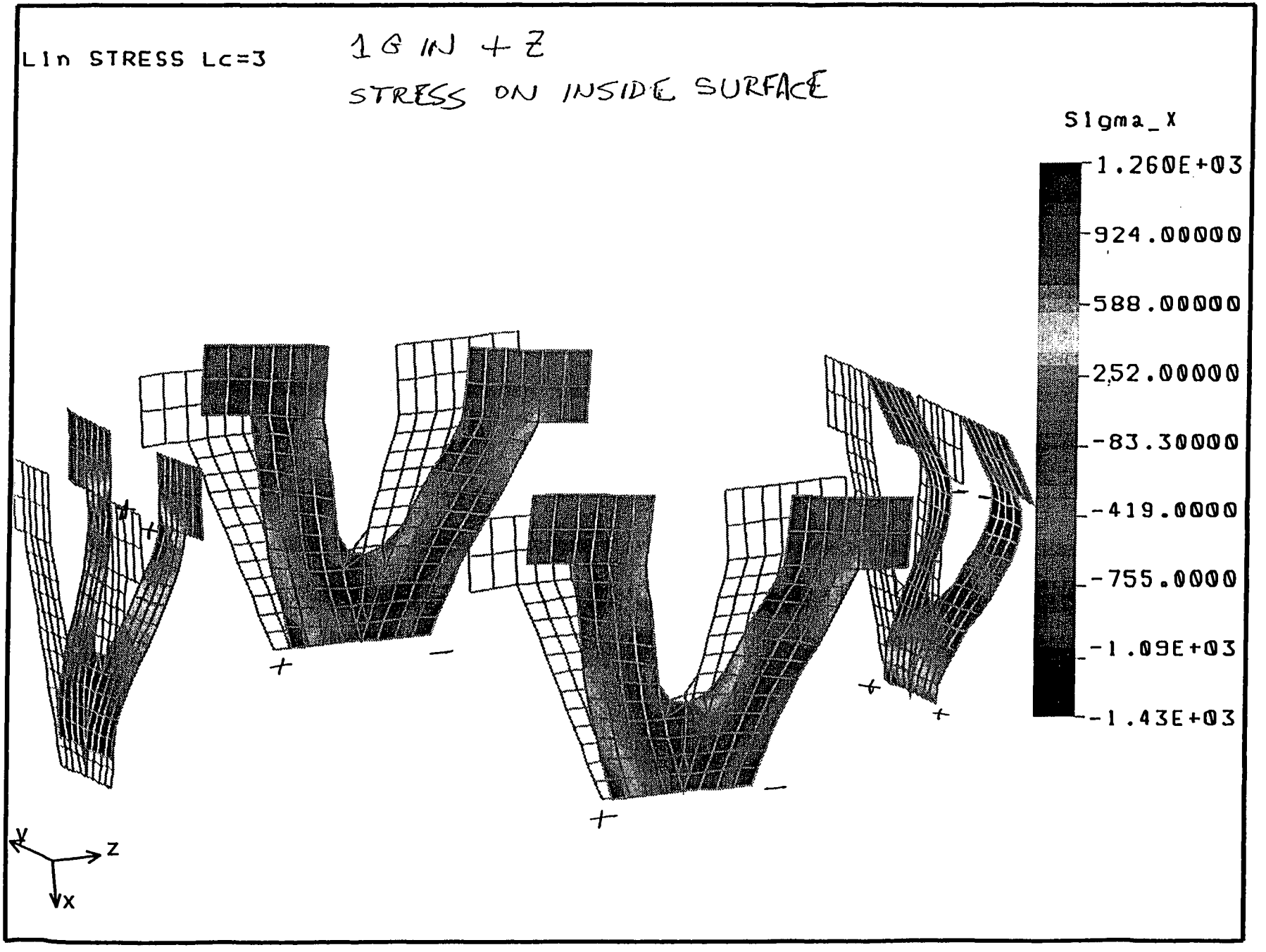

Lin STRESS Lc=1
1G IN +X
STRESS ON OUTSIDE SURFACE
Sigma_X
214.00
128.00
41.000
-45.70
-132.0
-219.0
-306.0
-392.0
-479.0
Y
Z
X


Lin STRESS Lc=1
1G IN +X
STRESS ON INSIDE SURFACE
Sigma_X
227.00
132.00
37.500
-57.50
-152.0
-247.0
-342.0
-437.0
-532.0
Y
Z
X


Lin STRESS Lc=2
1G IN + Y
STRESS ON OUTSIDE SURFACE
Sigma_X
1.450E+03
1.090E+03
734.00000
378.00000
21.700000
-334.0000
-690.0000
-1.05E+03
-1.40E+03
-
+
-
+
Y
Z
X


Lin STRESS Lc=2
1G IN +Y
STRESS ON INSIDE SURFACE
Sigma_X
1.380E+03
1.040E+03
696.00000
352.00000
7.5500000
-337.0000
-681.0000
-1.03E+03
-1.37E+03
Y
Z
X


Lin STRESS Lc=3
1G IN +Z
STRESS ON OUTSIDE SURFACE
Sigma_X
1.340E+03
952.00000
562.00000
171.00000
-220.0000
-610.0000
-1.00E+03
-1.39E+03
-1.78E+03
Y
Z
X


Lin STRESS Lc=3
1G IN +Z
STRESS ON INSIDE SURFACE
Sigma_X
1.260E+03
924.00000
588.00000
252.00000
-83.30000
-419.0000
-755.0000
-1.09E+03
-1.43E+03
Y
Z
X

Appendix C

M. FUREY

LOAD CYCLES FOR FRACTURE MECHANICS ANALYSIS

SINE SWEEP

THERE WILL BE A $\frac{1}{4}$ G SINE SWEEP IN EACH OF THE THREE AXIS, BEFORE AND AFTER RANDOM VIBRATION TESTING.

THE SWEEP WILL BE FROM 10 TO 600 HZ, AT A RATE OF ONE OCTAVE / MINUTE. (UPSWEEP ONLY)

WIDE BAND RESPONSE IS ASSUMED ALONG WITH A $Q = 20$.

THE NUMBER OF EQUIVALENT CYCLES AT σ_{MAX}

$$N_{eq} = \frac{60}{\lambda (\ln 2)} \Delta f$$

λ IS THE SWEEP RATE = 1 OCTAVE/MINUTE

$\Delta f = (600 - 10) = 590$ HZ

$$N_{eq} = \frac{60}{(1)(\ln 2)} (590) = 51,071.4 \text{ CYCLES AT } \sigma_{MAX}$$

USING A SCATTER FACTOR OF 4 TO ACCOUNT FOR THE SAFE LIFE REQUIREMENT:

$N_{TOTAL} = 204,286$ CYCLES / SWEEP (NOTE 2 SWEEPS WILL BE USED)

LOAD = INPUT LOAD x Q = $\frac{1}{4}$ G x 20 = 5 G

SINE SWEEP (CONT.)

INPUT LOAD DIRECTION	MAX 1G TENSILE STRESS	x 5G
X	532 PSI	2660 PSI
Y	1450	7250
Z	1780	8900

THE STRESSES IN THE THIRD COLUMN WILL BE USED ALONG WITH THE CYCLES CALCULATED ON THE PREVIOUS PAGE, IN BUILDING THE FLAGRO LOAD SCHEDULE.

NOTE: THE MAXIMUM STRESSES ARE VERY CONSERVATIVELY ASSUMED TO OCCUR AT THE SAME LOCATION ON THE SAME FLEXURE FOR ALL LOAD CASES THAT WILL BE USED FOR THE SAFE LIFE ANALYSIS.

M. FUREY 8-20-96

ABORT LANDING LOADS REF. SE11 C[b], P21
11 JAN. 1996

DIRECTION	DESIGN LIMIT ACCELERATIONS, G	STRESS FROM 1G ANALYSES	LIMIT STRESSES
X	±1.0	532 PSI	532
Y	±2.3	1450	3335
Z	±4.6	1780	8188
		TOTAL =	12,055 PSI

LIMIT STRESS FROM ABORT LANDING AS A PERCENT OF THE DESIGN LIMIT STRESS

$\left(12{,}055/33{,}540\right)(100) = 36\%$ USE 40%

Appendix D

M. Furey		**Aug. 12, 1996**										
Rayleigh	Distribution	Times Scatter		Random Vib.		**Random Vib Test**				% of max		
Distribution	Of cycles in	Factor		Input		Load		3 Sigma		limit stress		
Factors	60 sec	of 4		G^2/Hz	Q	Direction	Freq. (Hz)	Accel. (G)	Max Stress	(33540 psi)		
0.0171	1.026	4.104		0.015	10	X	375	28.199568	15002.17	0.4472919		
0.0306	1.836	7.344		0.015	10	y	84	13.346472	19352.384	0.57699415		
0.0575	3.45	13.8		0.015	10	Z	109	15.203377	27062.011	0.80685783		
0.0895	5.37	21.48										
0.1284	7.704	30.816		Random Vib.		**Acouistic Test**				% of max		
0.1637	9.822	39.288		Input		Load		3 Sigma		limit stress		
0.1802	10.812	43.248		G^2/Hz	Q	Direction	Freq. (Hz)	Accel. (G)	Max Stress	(33540 psi)		
0.1683	10.098	40.392		0.0116	10	X	226	19.251493	10241.794	0.30536059		
0.1207	7.242	28.968		0.015	10	y	83	13.26679	19236.846	0.57354938	USE with 83 Hz	
0.044	2.64	10.56		0.015	10	Z	67	11.91967	21217.012	0.63258832	<-- frequency to be	
	60	240									extra conservative	

Ground Transportation				**Air Transportation**			
Location 1 to Location 2		Milage		Location 1 to Location 2		Milage	
MIT	LMA/Ball	5000		TRW	Cape	5000	
LMA/Ball	MIT	5000					
MIT	Lincoln Lab	50					
Lincoln Lab	MIT	50					
MIT	MSFC	2500					
MSFC	TRW	3500					
	Total	16100					
For truck transport use a design limit load factor of +/- 3.5 G in all directions, and							
for air transport use a design limit load factor of +/- 3.0 G in all directions. The							
maximum stresses, due to 1 G loads in the X, Y and Z directions, will be multplied by							
these load factors and combined to give the maximum "limit tensile stress", no matter							
where or on what flexure they occur.							
				% of max			% of max
		Grnd Trans	Limit Load	limit stress	Air Trans	Limit Load	limit stress
Max Stress due to		Load Factor	Stress (psi)	(33540 psi)	Load Factor	Stress (psi)	(33540 psi)
1G in X	532	3.5	1862		3	1596	
1G in Y	1450	3.5	5075		3	4350	
1G in Z	1780	3.5	6230		3	5340	
		Total	13167	0.39257603	Total	11286	0.33649374
Truck Transportation Cycles			**Plane Transportation Cycles**				**Total**
% of Truck	Cycles in	Cycles in		% of Plane	Cycles for		**Transportation**
Limit Load	200 miles	16100 miles		Limit Load	each flight		**Cycles x 4**
100 to 90	2	161		100 to 90	4		660
90 to 80	3	241.5		90 to 80	5		986
80 to 70	10	805		80 to 70	12		3268
70 to 60	21	1690.5		70 to 60	23		6854
60 to 50	41	3300.5		60 to 50	44		13378
50 to 40	81	6520.5		50 to 40	85		26422
40 to 30	148	11914		40 to 30	153		48268
30 to 20	273	21976.5		30 to 20	279		89022
20 to 10	552	44436		20 to 10	563		179996
10 to 0	1096	88228		10 to 0	1116		357376

Lift off and Landing

The maximum stress on an individual flexure occurs during a lift off loading condition. These loads occur from the combination of the lift off vibro-acoustic disturbance with (low frequency) quasi- static loads. The stresses that thus occur will be conservatively treated as if they only result from high frequency events. The maximum stress, which we will designate as the limit stress, results from loads of 4.4 G in the X direction, -2.4 G in the Y direction and 15.9G in the Z direction. The first mode frequency associated with this loading condition is 67 Hz. The load factors for landing are +/- 1.0 in the X, +/- 2.3 in the Y, and +/-4.6 in the Z direction.

STS Payload Launch and Landing Fatigue Spectra

% of event	Launch		Landing	
Limit Load	Cycles	x 4	Cycles	x 4
100 to 90	1	4	1	4
90 to 80	3	12	1	4
80 to 70	5	20	3	12
70 to 60	12	48	3	12
60 to 50	46	184	3	12
50 to 40	78	312	3	12
40 to 30	165	660	13	52
30 to 20	493	1972	148	592
20 to 10	2229	8916	891	3564
10 to 0	110278	441112	18654	74616

Appendix E

M. Furey		Aug. 14, 1996											
ACIS Support Structure Flexure - Fracture Load Spectra (Number of Cycles from all causes as a percent of Limit Stress)													
				Random Vibration									
Percent of	Two 1/4 G Sine Sweeps in each axis			X	Y	Z		Acoustic Test					Percent of
Design Limit	x 4	x 4	x 4	60 sec x 4	60 sec x 4	60 sec x 4	Transportation	60 sec x 4	Lift off #1	Landing	Lift off #2	Total	Design Limit
Stress	X	Y	Z	@ 375 Hz	@ 84 Hz	@ 109 Hz	cycles x 4	@ 83 Hz	cycles x 4	cycles x 4	cycles x 4	Cycles	Stress
100 to 90									4		4	8	100 to 90
90 to 80						1247.832			12		12	1271.832	90 to 80
80 to 70						1504.2			20		20	1544.2	80 to 70
70 to 60						2341.32		950.184	48		48	3387.504	70 to 60
60 to 50					961.632	3358.944		2928.24	184		184	7616.816	60 to 50
50 to 40				4293	2963.52	4282.392		5818.632	312		312	17981.544	50 to 40
40 to 30				13230	5888.736	4714.032	4914	3589.584	660	5	660	33661.352	40 to 30
30 to 20		408572	408572	26289	7025.76	4402.728	46654	3352.536	1972	9	1972	908821.02	30 to 20
20 to 10				31365	2433.312	3157.512	137290	2404.344	8916	161	8916	194643.17	20 to 10
10 to 0	408572			14823	887.04	1151.04	537372	876.48	441112	19545	441112	1865450.6	10 to 0
										Sum of All Cycles equals		**3034386**	

Appendix F

FATIGUE CRACK GROWTH ANALYSIS

DATE: 09/20/96 TIME: 15:14:09

(computed: NASA/FLAGRO Version 2.03, March 1995.)

U.S. customary units [inches, ksi, ksi sqrt(in)]

PROBLEM TITLE

PSSS Safe Life Analysis

GEOMETRY

MODEL: CC01-Corner crack in plate or bar (2D)

Plate Thickness, t = 0.1880
Plate Width, W = 2.0000

FLAW SIZE (Standard NASA JSC NDE):

a (init.) = 0.1000
c (init.) = 0.1000
a/c (init.) = 1.000

MATERIAL

MATL 1: Ti-6Al-4V; BA(1900F/.5h+1325F/2h)
Plt&Sht; LA,DA,3.5% NaCl

Material Properties:

Matl No.	UTS	YS	K1e	K1c	Ak	Bk	Thk	Kc	KIscc
1	135.0	120.0	100.0	80.0	1.00	0.50	0.188	118.9	

Matl No.	Crack Growth Eqn Constants C	n	p	q	DKo	Rcl	Alpha	Smax/SIGo
1	0.900E-09	3.250	0.25	0.75	3.50	0.70	2.50	0.30

PSSS Safe Life Analysis
MODEL: CC01

FATIGUE SCHEDULE BLOCK INPUT TABLE

PSSS Flexure Load Schedule

[Note: Stress = Input Value * Stress Factor]

Stress Scaling Factors for Block Case: 1

Scale Factor for Stress S0: 1.0000
Scale Factor for Stress S1: 1.0000
Scale Factor for Stress S2: 1.0000

Total No. of Blocks in Schedule = 1

Block Number and Case Correspondences

Block Number			Block Case No.
From	-	To	
1	-	1	1

SINGLE DISTINCT BLOCK

S T E P	M: A: T: L:	NUMBER OF FATIGUE CYCLES	S0 (t1)	S0 (t2)	S1 (t1)	S1 (t2)
1:	1:	8.00	12.43:	-12.43:	7.87:	-7.87:
2:	1:	1272.00	11.19:	-11.19:	7.08:	-7.08:
3:	1:	1544.00	9.94:	-9.94:	6.30:	-6.30:
4:	1:	3388.00	8.70:	-8.70:	5.51:	-5.51:
5:	1:	7617.00	7.46:	-7.46:	4.72:	-4.72:
6:	1:	17982.00	6.21:	-6.21:	3.93:	-3.93:
7:	1:	33661.00	4.97:	-4.97:	3.15:	-3.15:
8:	1:	908821.00	3.73:	-3.73:	2.36:	-2.36:
9:	1:	194643.00	2.49:	-2.49:	1.57:	-1.57:
10:	1:	1865451.00	1.24:	-1.24:	0.79:	-0.79:

S T E P	M: A: T: L:	NUMBER OF FATIGUE CYCLES	S2 (t1)	S2 (t2)	S (t1)	S (t2)
1:	1:	8.00	12.43:	-12.43:	12.43:	-12.43:
2:	1:	1272.00	11.19:	-11.19:	11.19:	-11.19:
3:	1:	1544.00	9.94:	-9.94:	9.94:	-9.94:
4:	1:	3388.00	8.70:	-8.70:	8.70:	-8.70:
5:	1:	7617.00	7.46:	-7.46:	7.46:	-7.46:
6:	1:	17982.00	6.21:	-6.21:	6.21:	-6.21:
7:	1:	33661.00	4.97:	-4.97:	4.97:	-4.97:
8:	1:	908821.00	3.73:	-3.73:	3.73:	-3.73:
9:	1:	194643.00	2.49:	-2.49:	2.49:	-2.49:
10:	1:	1865451.00	1.24:	-1.24:	1.24:	-1.24:

Environmental Crack Growth Check for Sustained Stresses
(Kmax less than KIscc): NOT SET

PSSS Safe Life Analysis
MODEL: CC01

FATIGUE SCHEDULE BLOCK STRESS TABLE

PSSS Flexure Load Schedule

S T E P	M: A: T: L:	NUMBER OF FATIGUE CYCLES	S0 (ksi) (t1)	S0 (ksi) (t2)	S1 (ksi) (t1)	S1 (ksi) (t2)
1:	1:	8.00 :	12.43:	-12.43:	7.87:	-7.87:
2:	1:	1272.00 :	11.19:	-11.19:	7.08:	-7.08:
3:	1:	1544.00 :	9.94:	-9.94:	6.30:	-6.30:
4:	1:	3388.00 :	8.70:	-8.70:	5.51:	-5.51:
5:	1:	7617.00 :	7.46:	-7.46:	4.72:	-4.72:
6:	1:	17982.00 :	6.21:	-6.21:	3.93:	-3.93:
7:	1:	33661.00 :	4.97:	-4.97:	3.15:	-3.15:
8:	1:	908821.00 :	3.73:	-3.73:	2.36:	-2.36:
9:	1:	194643.00 :	2.49:	-2.49:	1.57:	-1.57:
10:	1:	1865451.00 :	1.24:	-1.24:	0.79:	-0.79:

S T E P	M: A: T: L:	NUMBER OF FATIGUE CYCLES	S2 (ksi) (t1)	S2 (ksi) (t2)	S (ksi) (t1)	S (ksi) (t2)
1:	1:	8.00 :	12.43:	-12.43:	0.00:	0.00:
2:	1:	1272.00 :	11.19:	-11.19:	0.00:	0.00:
3:	1:	1544.00 :	9.94:	-9.94:	0.00:	0.00:
4:	1:	3388.00 :	8.70:	-8.70:	0.00:	0.00:
5:	1:	7617.00 :	7.46:	-7.46:	0.00:	0.00:
6:	1:	17982.00 :	6.21:	-6.21:	0.00:	0.00:
7:	1:	33661.00 :	4.97:	-4.97:	0.00:	0.00:
8:	1:	908821.00 :	3.73:	-3.73:	0.00:	0.00:
9:	1:	194643.00 :	2.49:	-2.49:	0.00:	0.00:
10:	1:	1865451.00 :	1.24:	-1.24:	0.00:	0.00:

Environmental Crack Growth Check for Sustained Stresses
(Kmax less than KIscc): NOT SET

PSSS Safe Life Analysis
MODEL: CC01

ANALYSIS RESULTS:

FINAL RESULTS:
Critical Crack Size has NOT been reached.
at Cycle No. 1865451.00 of Load Step No. 10
Step description:
of Block No. 1 of Schedule No. 1
Crack Sizes: a = 0.126515 , c = 0.146054 , a/c = 0.86622