Fermilab

SDC SOLENOID DESIGN NOTE #143

TITLE: Report of Feasibility Study of Aluminum Isogrid for Outer Vacuum Shell

AUTHOR: Paul Slysh, President, PS Associates, Inc., San Diego, California

DATE: May 9, 1991

ABSTRACT: On March 12, 1991, Fermilab entered into a subcontract (Purchase Order #B14690) with PS Associates, Inc. to perform a feasibility study and preliminary design of an aluminum isogrid structure suitable for the outer vacuum shell of the SDC solenoid. A copy of the PO and the scope of work statement are included as an appendix to this design note.

On May 13 we received the final report of the work done under the subcontract. The entire report is given in this design note. Figure 1 summarizes the results of the calculations. It shows that an effective thickness of about 0.25 inches (0.213 inches for a flanged isogrid made of 2219-T851) can be achieved with isogrid. A solid aluminum shell would be 0.886 inches thick. Therefore, use of a flanged isogrid of 2219 will have a thickness 0.190 X_0 less than a solid shell.

PS▲A PS ASSOCIATES, INC.

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May 9, 1991

Mr. Chuck Grozis
Fermi National Accelerator Laboratory
P. O. Box 500
Batavia, Ill. 60510

Subject: SDC Vacuum Structure

Dear Chuck,

The following attached items, in addition to previously submitted data, are in fulfillment of the Fermi National Accelerator Laboratory Purchase Order B14690.

1. Figure 1. Trade data for the comparative evaluation of Weldalite 049, Aluminum 2219-T851 and Aluminum 5081-T0 for the construction of the SDC Vacuum Structure in conventional flanged and unflanged isogrid. These trades are based on compliance with Section VIII, Division 1 of the ASME Pressure Vessel Code and conditions outlined in Ronald W Fast's letter of 2/21/91.

2. SST Isogrid Structures print out of trade study partly supporting the selections made in item 1 above.

3. SST generated rib cross section and isogrid flat pattern for a 4'x 8' test specimen.

4. Cost and delivery estimates for the production of specimen in item 3 above.

5. Report on the results of a COSMOS/M finite element analysis of the SDC Vacuum Structure for fixed and free (pin) end supports. The nominal deflections in a flat plate bulkhead are also evaluated.

6. Proposed outline of the next (phase 2, follow on) detailed design and manufacturing planning program to meet a mid 1993 hardware delivery schedule.

Sincerely,

Paul Slysh

Paul Slysh, President

Figure 1.

	049 Weldalite		2219 T851 Alum.		5083-T0 Alum.	
	Flanged Isogrid	Unflanged Isogrid	Flanged Isogrid	Unflanged Isogrid	Flanged Isogrid	Unflanged Isogrid
Plate Thickness (Inches)	1.1	1.2	1.1 * ~~1.2~~	1.1	1.2	1.1
Structure Weight (Lbs.)	3059	2899	3928	4278	5270	5448
Effective thickness (Inches)	.174	.165	.213	.232	.303 * ~~.311~~	.313
Node spacing (Inches)	6.91	5.22	6.91	4.21	6.91	4.21

* Apparent typographical error. (RWF).

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SST ISO - ISOGRID SHELL STRUCTURES

FERMI CONVENTIONAL ISOGRID ANALYSIS --- TRADES ----
SECT: 1 ANG: 1 WELDALITE-049 ENGLISH UNITS
MACHINED/CAST FLANGED CROSS SECTION 9 May 1991
SDC Vacuum Structure Ta= 5 SPEC. FILE: IFERMI

Da$	Zo$	Zm$	Fa$	Ei$	Em$	N1$	U$(1)
U$(2)	M$		Bn$( )	St$	O1$	O2$	O3$
Td	Bd	Poii	Faii	Fs	Ff(1)	Ff(2)	Fl_(1)
Fy	Fu	Nu	E	G	Rh	Ym	Wd
Wx	Wm	Tm	Bm	S1	Omii	Oxii	Odii
Cxii	Ssii	Fii	Bo	B5	B6	W5	
Ad	P_(1)	Tf	Tf_(1)	Tf_(2)	Nx	Ei_req	V_mises$
Mii	P	Skinb$	Nro	Rc	R	R0	E1
Et	Eb	Ew	C0	C1	Cv	Ga	R1
Keff	Kribax	Kribtor	Lf	Acone$	Cmin	B2min	Rib_step
Uf	Ug	Us	Gen$				

9 May 1	N	N	N	N	N	N	Y
N	WELDALITE-049		UFERMI1	RFERMI	Y	N	N
.0100	.0500	2	0	50160	0	0	60000
85000	88000	.330	1.17E+7	4.40E+6	.097	.010	.100
2.2000	1.0000	.0700	.4000	.1000	120	216	9
0	4	0	.060	.060	.060	1	
.002	-30.0	100.0	0.0	100.0	175	0.0E+00	N
106	-30	N	12	80	.09	.09	.02
.004	.01	.004	.5	10.2	23.1	.61	.313
1.38	1.4	1.4	40	N	.11	.095	0
4	1	1	Y				

No	W	B	T	B2	C	Mg	Wf(1)
Mp(1)	Mp(2)	Ms	At	I	X	Tb_(1)	Ei
A	R2	Mh_min	Mhh_min	Gaa	Mg_shear	Mrib3781	Mha_min
Mgg	M_colx	M_coly	I_y	Knom	Wa_(1)	T2	Mribih

120	1.0000	.4000	.0900	.0950	.1100	.1515	3349.91
1.0505	.1830	32.3442	.503944	.04581	.803169	.19085	2.233E+12
4.8369	.4655	.1538	.1515	.6192	121100	0	.1538
37.2	33.76	0	0	23.271	.0185	.09	54.54

120	1.1000	.5000	.0800	.0950	.1100	.4776	3481.01
.8351	.0046	23.9457	.446272	.06285	.832539	.19832	2.141E+12
4.8369	.5155	.4826	.4776	.6466	148400	0	.4826
43.57	33.08	0	0	26.18	.0192	.08	52.17

129	1.1000	.4500	.0800	.0950	.1100	.4786	3562.45
.8837	.0449	28.1458	.419990	.05843	.831467	.20296	2.162E+12
4.4995	.4905	.4836	.4786	.6458	148700	0	.4835
43.74	33.68	0	0	24.353	.0197	.08	52.7

129	1.2000	.4000	.0800	.0950	.1100	.6635	3634.14
.9290	.0824	28.4120	.423990	.06842	.913056	.20704	2.181E+12
4.4995	.4655	.6701	.6635	.6557	164400	0	.6701
47.58	34.15	0	0	24.353	.0201	.08	53.2

129	1.0000	.5000	.0800	.0950	.1100	.2940	3485.72
.8384	.0073	27.8795	.415990	.04886	.750592	.19859	2.143E+12

4.4995	.5155	.2976	.294	.6342	132700	0	.2976
39.77	33.18	0	0	24.353	.0193	.08	52.2

111	1.0000	.4000	.0900	.0950	.1100	.0934	3213.56
.9565	.1052	26.9761	.477642	.04515	.794809	.18308	2.192E+12
5.2291	.4655	.09548	.09341	.616	115600	0	.09546
35.67	32.66	0	0	25.158	.0178	.09	53.5

111	1.1000	.4000	.0900	.0950	.1100	.3153	3343.46
1.0491	.1819	27.4919	.487142	.05745	.870733	.19048	2.232E+12
5.2291	.4655	.3188	.3153	.632	135400	0	.3188
40.77	33.81	0	0	25.158	.0185	.09	54.52

102	1.1000	.4000	.0900	.0950	.1100	.2433	3196.57
.9476	.0978	22.5558	.487142	.05745	.870733	.18211	2.188E+12
5.6905	.4655	.2464	.2433	.6285	128700	0	.2464
38.96	32.55	0	0	27.378	.0177	.09	53.4

102	1.2000	.4000	.0900	.0950	.1100	.4722	3314.92
1.0328	.1683	22.9560	.496642	.07156	.945665	.18886	2.225E+12
5.6905	.4655	.4768	.4722	.6428	148800	0	.4768
44.02	33.61	0	0	27.378	.0183	.09	54.34

102	1.0000	.4000	.0900	.0950	.1100	.0334	3078.22
.8625	.0273	22.1556	.477642	.04515	.794809	.17537	2.152E+12
5.6905	.4655	.03517	.03338	.6124	109900	0	.03516
34.09	31.42	0	0	27.378	.017	.09	52.47

93	1.0000	.5000	.0900	.0950	.1100	.0769	3055.45
.8584	.0239	18.2119	.488642	.05105	.778155	.17407	2.150E+12
6.2412	.5155	.07891	.07685	.6164	113700	0	.07889
35.06	31.2	0	0	30.027	.0169	.09	52.42

93	1.1000	.4000	.0900	.0950	.1100	.1687	3050.87
.8461	.0137	18.1640	.487142	.05745	.870733	.17381	2.145E+12
6.2412	.4655	.1714	.1687	.6245	121800	0	.1713
37.08	31.22	0	0	30.027	.0169	.09	52.29

93	1.2000	.4000	.0900	.0950	.1100	.3840	3157.85
.9237	.0780	18.4673	.496642	.07156	.945665	.17991	2.178E+12
6.2412	.4655	.3882	.384	.639	140800	0	.3882
41.89	32.26	0	0	30.027	.0175	.09	53.14

84	1.1000	.5500	.0900	.0950	.1100	.2602	3059.50
.8664	.0305	14.6813	.503642	.06809	.844009	.17430	2.153E+12
6.9099	.5405	.2635	.2602	.6313	129900	0	.2635
39.11	31.29	0	0	33.244	.0169	.09	52.51

84	1.2000	.4500	.0900	.0950	.1100	.3581	3054.31
.8553	.0213	14.6460	.502142	.07588	.93591	.17401	2.148E+12
6.9099	.4905	.3621	.3581	.6385	138300	0	.3621
41.16	31.32	0	0	33.244	.0169	.09	52.39

84	1.3000	.4000	.0900	.0950	.1100	.5105	3097.95
.8848	.0458	14.7401	.506142	.08756	1.01966	.17649	2.161E+12
6.9099	.4655	.5158	.5105	.6478	151400	0	.5157
44.38	31.77	0	0	33.244	.0171	.09	52.71

OPTIMUM WEIGHT IS: 3051 AT OR ABOVE LAST ENTRY
NUMBER IF OPTIMIZATION TRIALS PERFORMED IS: 16

SST ISO - ISOGRID SHELL STRUCTURES

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FERMI      CONVENTIONAL ISOGRID ANALYSIS    ---  TRADES  ----
SECT: 1    ANG: 1     WELDALITE-049        ENGLISH UNITS
MACHINED UNFLANGED CROSS SECTION            9 May 1991
SDC Vacuum Structure Ta= 5     SPEC. FILE: IFERMI
-----------------------------------------------------------------------------
Da$        Zo$        Zm$        Fa$        Ei$        Em$        Nl$        U$(1)
U$(2)      M$                    Bn$( )     St$        Ol$        O2$        O3$
Td         Bd         Poii       Faii       Fs         Ff(1)      Ff(2)      Fl_(1)
Fy         Fu         Nu         E          G          Rh         Ym         Wd
Wx         Wm         Tm         Bm         S1         Omii       Oxii       Odii
Cxii       Ssii       Fii        Bo         B5         B6         W5
Ad         P_(1)      Tf         Tf_(1)     Tf_(2)     Nx         Ei_req     V_mises$
Mii        P          Skinb$     Nro        Rc         R          RO         El
Et         Eb         Ew         CO         Cl         Cv         Ga         Rl
Keff       Kribax     Kribtor    Lf         Acone$     Cmin       B2min      Rib_step
Uf         Ug         Us         Gen$

 9 May 1   N          N          N          N          N          N          Y
N          WELDALITE-049         UFERMI1    RFERMI     Y          N          N
 .0100      .0500      2          0          50160          0          0      60000
 85000      88000      .330       1.17E+7    4.40E+6    .097       .010       .100
2.2000     1.0000      .0700      .1000      .1000      120        216        9
  0          4          0         .060       .060       .060        1
  .002     -30.0      100.0       0.0       100.0       175       0.0E+00    N
 106       -30        N          12         80         0          .09        .02
 .004       .01        .004       .5         10.2       23.1       .61        .313
 1.67       1.4        1.4        40         N          0          .017       0
 1          1          1          Y
=============================================================================
No         W          B          T          B2         C          Mg         Wf(1)
Mp(1)      Mp(2)      Ms         At         I          X          Tb_(1)     Ei
A          R2         Mh_min     Mhh_min    Gaa        Mg_shear   Mrib3781   Mha_min
Mgg        M_colx     M_coly     I_y        Knom       Wa_(1)     T2         Mribih
=============================================================================
120        1.0000     .1500      .1100      .1500      0.0000     .0172      3764.80
  4.9937     3.9642   58.6187    .597743    .03516     .832893    .21449     2.670E+12
 4.8369     .313       .01791     .01717     .5895      112200    64.91      .0179
 36.25      41.66      0          0          19.04      .0208     .11        64.91
-----------------------------------------------------------------------------
120        1.1000     .1500      .0700      .1500      0.0000     .1245      3339.41
  3.4341     2.6725   16.1357    .344568    .03943     .817831    .19025     2.011E+12
 4.8369     .313       .1272      .1245      .627       116700    47.76      .1272
 35.33      32.02      0          0          29.92      .0185     .07        47.76
-----------------------------------------------------------------------------
120        1.2000     .1000      .0700      .1000      0.0000     .0434      2860.65
  2.9861     2.3015   14.4186    .303068    .03754     .940656    .16297     1.825E+12
 4.8369     .313       .04605     .04344     .6291      107900    20.12      .04604
 32.47      28.81      0          0          29.92      .0158     .07        26.51
-----------------------------------------------------------------------------
120        1.3000     .1099      .0700      .1099      0.0000     .2453      3145.02
  3.0810     2.3800   14.7822    .313068    .04705     1.00901    .17918     1.870E+12
 4.8369     .313       .2493      .2453      .6434      125700    21.6       .2493
 37         29.82      0          0          29.92      .0174     .07        27.91
-----------------------------------------------------------------------------
129        1.2000     .1000      .0700      .1000      0.0000     .0948      2985.38
  3.0665     2.3681   17.1864    .303068    .03754     .940656    .17008     1.863E+12
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4.4995	.313	.09768	.09479	.6317	112700	20.96	.09767
33.8	29.71	0	0	27.832	.0165	.07	27.07

129	1.3000	.1108	.0700	.1108	0.0000	.3063	3306.34
3.1685	2.4525	17.6381	.313068	.04705	1.00901	.18837	1.911E+12
4.4995	.313	.3107	.3063	.6458	131400	22.58	.3107
38.53	30.76	0	0	27.832	.0183	.07	29.1

129	1.1000	.1000	.1100	.1000	0.0000	.0084	3479.57
4.6899	3.7126	63.7753	.531096	.03285	.941985	.19824	2.548E+12
4.4995	.313	.00926	.00836	.5933	110600	38.76	.009247
35.48	40.25	0	0	17.712	.0192	.11	51.35

111	1.2000	.1000	.0800	.1000	0.0000	.0258	2899.44
3.3385	2.5933	18.0134	.342184	.03888	.963004	.16518	1.971E+12
5.2291	.313	.02794	.02581	.6201	107700	21.87	.02793
32.93	30.92	0	0	28.303	.016	.08	29.53

111	1.3000	.1088	.0700	.1088	0.0000	.1825	2984.81
2.9935	2.3076	12.2077	.300050	.04615	.997906	.17005	1.829E+12
5.2291	.313	.1861	.1825	.6406	119900	20.21	.1861
35.43	28.9	0	0	32.346	.0165	.07	26.68

111	1.1000	.1500	.0700	.1500	0.0000	.0686	3182.00
3.3201	2.5781	13.2788	.331550	.0386	.808126	.18128	1.959E+12
5.2291	.313	.07108	.06864	.6246	111400	46.5	.07106
33.81	30.83	0	0	32.346	.0176	.07	46.5

OPTIMUM WEIGHT IS: 2861 AT OR ABOVE LAST ENTRY
NUMBER IF OPTIMIZATION TRIALS PERFORMED IS: 10

SST ISO - ISOGRID SHELL STRUCTURES

FERMI CONVENTIONAL ISOGRID ANALYSIS --- TRADES ----
SECT: 1 ANG: 1 ALUM 2219-T851 ENGLISH UNITS
MACHINED/CAST FLANGED CROSS SECTION 8 May 1991
SDC Vacuum Structure Ta= 5 SPEC. FILE: IFERMI

Da$	Zo$	Zm$	Fa$	Ei$	Em$	Nl$	U$(1)
U$(2)	M$		Bn$( )	St$	O1$	O2$	O3$
Td	Bd	Poii	Faii	Fs	Ff(1)	Ff(2)	Fl_(1)
Fy	Fu	Nu	E	G	Rh	Ym	Wd
Wx	Wm	Tm	Bm	S1	Omii	Oxii	Odii
Cxii	Ssii	Fii	Bo	B5	B6	W5	
Ad	P_(1)	Tf	Tf_(1)	Tf_(2)	Nx	Ei_req	V_mises$
Mii	P	Skinb$	Nro	Rc	R	RO	El
Et	Eb	Ew	CO	Cl	Cv	Ga	Rl
Keff	Kribax	Kribtor	Lf	Acone$	Cmin	B2min	Rib_step
Uf	Ug	Us	Gen$				
8 May 1	N	N	N	N	N	N	Y
N	ALUM 2219-T851		UFERMI1	RFERMI	Y	N	N
.0100	.0500	2	0	36000	0	0	60000
48000	62000	.330	1.08E+7	4.06E+6	.102	.010	.100
2.2000	1.0000	.0700	.4000	.1000	120	216	9
0	4	0	.060	.060	.060	1	
.002	-30.0	100.0	0.0	100.0	175	0.0E+00	N
101	-30	N	19	80	.09	.09	.02
.004	.01	.004	.5	10.2	23.1	.61	.313
1.38	1.4	1.4	40	N	.11	.095	0
4	1	1	Y				

No	W	B	T	B2	C	Mg	Wf(1)
Mp(1)	Mp(2)	Ms	At	I	X	Tb_(1)	Ei
A	R2	Mh_min	Mhh_min	Gaa	Mg_shear	Mrib3781	Mha_min
Mgg	M_colx	M_coly	I_y	Knom	Wa_(1)	T2	Mribih
120	1.0000	.5000	.1300	.0950	.1100	.2873	4353.45
-.1077	.0220	54.2832	.639799	.05248	.804298	.23586	2.786E+12
4.8369	.5155	.2896	.2873	.6086	137700	0	.2894
42.97	38.8	0	0	16.111	.0241	.13	41.8
120	1.1000	.4000	.1300	.0950	.1100	.3969	4350.24
-.1167	.0128	54.1564	.638299	.05908	.898695	.23569	2.780E+12
4.8369	.4655	.4023	.3969	.6169	147700	0	.4021
42.87	38.7	0	0	16.111	.024	.13	41.7
120	1.2000	.4000	.1300	.0950	.1100	.6514	4499.16
-.0601	.0712	54.9596	.647799	.07396	.979067	.24376	2.819E+12
4.8369	.4655	.6654	.6514	.6319	171000	0	.6652
43.49	39.32	0	0	16.111	.0249	.13	42.32
129	1.1000	.4000	.1300	.0950	.1100	.4651	4502.18
-.0610	.0703	54.9465	.638299	.05908	.898695	.24392	2.819E+12
4.4995	.4655	.4723	.4651	.6203	154200	0	.472
43.49	39.31	0	0	14.987	.0249	.13	42.31
129	1.2000	.4000	.1300	.0950	.1100	.7317	4663.62
-.0003	.1331	55.8099	.647799	.07396	.979067	.25267	2.861E+12

4.4995	.4655	.7484	.7317	.6351	178500	0	.7481
44.16	39.98	0	0	14.987	.0258	.13	42.98
129	1.0000	.4000	.1300	.0950	.1100	.2181	4340.74
-.1218	.0074	54.0831	.628799	.04619	.817406	.23518	2.776E+12
4.4995	.4655	.2197	.2181	.6035	131400	0	.2196
41.6	38.64	0	0	14.987	.024	.13	41.64
111	1.0000	.4000	.1400	.0950	.1100	.1191	4233.79
.0195	.1535	56.0905	.708633	.04681	.826561	.22938	2.874E+12
5.2291	.4655	.12	.1191	.5917	123000	0	.12
39.69	40.2	0	0	16.173	.0234	.14	43.2
111	1.1000	.5000	.1300	.0950	.1100	.4635	4343.24
-.1117	.0179	54.2266	.649299	.06679	.884402	.23531	2.783E+12
5.2291	.5155	.4711	.4635	.6214	153800	0	.4708
42.92	38.76	0	0	17.417	.024	.13	41.76
102	1.1000	.4000	.1400	.0950	.1100	.2751	4221.99
.0166	.1505	56.0494	.718133	.05995	.909809	.22874	2.872E+12
5.6905	.4655	.2769	.2751	.6047	137300	0	.2768
43.42	40.17	0	0	17.6	.0233	.14	43.17
102	1.2000	.5000	.1300	.0950	.1100	.6299	4308.68
-.1242	.0050	54.0495	.658799	.0832	.963638	.23344	2.774E+12
5.6905	.5155	.6439	.6299	.6322	168700	0	.6436
42.78	38.62	0	0	18.954	.0238	.13	41.62
102	1.0000	.4000	.1400	.0950	.1100	.0569	4097.54
-.0315	.1008	55.3667	.708633	.04681	.826561	.22200	2.838E+12
5.6905	.4655	.05754	.05686	.5872	117000	0	.05753
38	39.64	0	0	17.6	.0226	.14	42.64
93	1.0000	.4500	.1400	.0950	.1100	.0484	4020.41
-.0570	.0744	55.0033	.714133	.05007	.820619	.21782	2.820E+12
6.2412	.4905	.04902	.04836	.587	116100	0	.04901
37.71	39.36	0	0	19.303	.0222	.14	42.36
93	1.1000	.4000	.1400	.0950	.1100	.1975	4074.76
-.0386	.0935	55.2654	.718133	.05995	.909809	.22076	2.833E+12
6.2412	.4655	.1989	.1975	.5998	129900	0	.1988
41.39	39.56	0	0	19.303	.0225	.14	42.56
84	1.1000	.4000	.1400	.0950	.1100	.1171	3928.68
-.0938	.0364	50.2961	.718133	.05995	.909809	.21285	2.794E+12
6.9099	.4655	.1181	.1171	.5943	122300	0	.1181
39.27	38.95	0	0	21.371	.0217	.14	41.95
84	1.2000	.4000	.1400	.0950	.1100	.3256	4029.41
-.0542	.0773	50.8121	.727633	.07513	.992189	.21831	2.822E+12
6.9099	.4655	.3285	.3256	.6103	141500	0	.3283
43.54	39.39	0	0	21.371	.0223	.14	42.39
84	1.0000	.5000	.1400	.0950	.1100	.0291	3932.27
-.0875	.0429	50.3776	.719633	.05327	.814767	.21304	2.799E+12
6.9099	.5155	.02966	.02906	.5859	114100	0	.02965
37.13	39.02	0	0	21.371	.0217	.14	42.02
75	1.1000	.4500	.1400	.0950	.1100	.0896	3831.03
-.1285	.0005	39.4997	.723633	.06394	.903312	.20756	2.770E+12

7.7391	.4905	.09053	.08959	.5927	119600	0	.09051
38.49	38.57	0	0	23.936	.0212	.14	41.57
75	1.2000	.4000	.1400	.0950	.1100	.2270	3872.91
-.1137	.0159	39.6544	.727633	.07513	.992189	.20983	2.780E+12
7.7391	.4655	.2287	.227	.6041	132200	0	.2286
41.83	38.73	0	0	23.936	.0214	.14	41.73
75	1.0000	.6000	.1400	.0950	.1100	.0436	3879.35
-.1025	.0274	39.7703	.730633	.05954	.803329	.21018	2.788E+12
7.7391	.5655	.04429	.0436	.5877	115400	0	.04428
37.44	38.86	0	0	23.936	.0214	.14	41.86
66	1.1000	.6500	.1400	.0950	.1100	.1922	3845.55
-.1142	.0154	30.4536	.745633	.07933	.878283	.20835	2.779E+12
8.7944	.5905	.1937	.1922	.6013	129000	0	.1937
41	38.73	0	0	27.2	.0213	.14	41.73
66	1.2000	.5500	.1400	.0950	.1100	.2950	3843.41
-.1191	.0103	30.4141	.744133	.08932	.971409	.20823	2.776E+12
8.7944	.5405	.2976	.295	.6096	138400	0	.2974
42.81	38.68	0	0	27.2	.0212	.14	41.68
66	1.3000	.4500	.1400	.0950	.1100	.3797	3838.11
-.1240	.0052	30.3746	.742633	.09814	1.06619	.20794	2.772E+12
8.7944	.4905	.3848	.3797	.616	146100	0	.3846
42.76	38.62	0	0	27.2	.0212	.14	41.62
66	1.4000	.4000	.1400	.0950	.1100	.5183	3873.29
-.1109	.0187	30.4800	.746633	.1121	1.15448	.20985	2.782E+12
8.7944	.4655	.5278	.5183	.6251	158700	0	.5276
42.9	38.77	0	0	27.2	.0214	.14	41.77

OPTIMUM WEIGHT IS: 3831 AT OR ABOVE LAST ENTRY
NUMBER IF OPTIMIZATION TRIALS PERFORMED IS: 23

SST ISO - ISOGRID SHELL STRUCTURES

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FERMI      CONVENTIONAL ISOGRID ANALYSIS    ---  TRADES  ----
SECT: 1    ANG: 1     ALUM 2219-T851       ENGLISH UNITS
MACHINED UNFLANGED CROSS SECTION          9 May 1991
SDC Vacuum Structure Ta= 5     SPEC. FILE: IFERMI
-----------------------------------------------------------------------------
Da$        Zo$        Zm$        Fa$        Ei$        Em$        N1$        U$(1)
U$(2)      M$                    Bn$( )     St$        O1$        O2$        O3$
Td         Bd         Poii       Faii       Fs         Ff(1)      Ff(2)      Fl_(1)
Fy         Fu         Nu         E          G          Rh         Ym         Wd
Wx         Wm         Tm         Bm         S1         Omii       Oxii       Odii
Cxii       Ssii       Fii        Bo         B5         B6         W5
Ad         P_(1)      Tf         Tf_(1)     Tf_(2)     Nx         Ei_req     V_mises$
Mii        P          Skinb$     Nro        Rc         R          RO         El
Et         Eb         Ew         CO         Cl         Cv         Ga         Rl
Keff       Kribax     Kribtor    Lf         Acone$     Cmin       B2min      Rib_step
Uf         Ug         Us         Gen$

 9 May 1   N          N          N          N          N          N          Y
N          ALUM 2219-T851        UFERMI1    RFERMI     Y          N          N
 .0100      .0500      2          0          36000          0          0      60000
 48000      62000      .330       1.08E+7    4.06E+6    .102       .010       .100
2.2000     1.0000     .0700      .1000      .1000      120        216         9
  0          4          0         .060       .060       .060        1
  .002     -30.0      100.0       0.0       100.0       175       0.0E+00    N
 101       -30        N          19         80         0          .09        .02
 .004       .01        .004      .5         10.2       23.1       .61        .313
 1.67       1.4        1.4       40         N          0          .017       0
 4          1          1         Y
=============================================================================
No         W          B          T          B2         C          Mg         Wf(1)
Mp(1)      Mp(2)      Ms         At         I          X          Tb_(1)     Ei
A          R2         Mh_min     Mhh_min    Gaa        Mg_shear   Mrib3781   Mha_min
Mgg        M_colx     M_coly     I_y        Knom       Wa_(1)     T2         Mribih
=============================================================================
120        1.0000     .1500      .1500      .1500      0.0000     .0029      4614.03
   .3487      .4936   60.7658    .759295    .03535     .840605    .24998     3.135E+12
 4.8369     .313       .002909   .00288     .5718      113700     46.82      .002897
 37.89      43.82      0          0         13.963     .0255      .15        46.82
-----------------------------------------------------------------------------
120        1.1000     .1500      .1400      .1500      0.0000     .2283      4658.08
   .1910      .3307   58.5264    .694811    .04644     .915561    .25237     3.029E+12
 4.8369     .313       .2295     .2283      .5957      134100     45.08      .2295
 43.08      42.08      0          0         14.96      .0257      .14        45.08
-----------------------------------------------------------------------------
129        1.1000     .1000      .1600      .1000      0.0000     .0098      4503.72
   .4310      .5787   61.9353    .720924    .03296     .947804    .24401     3.199E+12
 4.4995     .313       .009775   .009799    .5704      114800     47.72      .009763
 38.33      44.72      0          0         12.177     .0249      .16        47.72
-----------------------------------------------------------------------------
129        1.2000     .1000      .1400      .1000      0.0000     .1956      4321.97
   .0014      .1348   55.8340    .586803    .04193     1.02108    .23416     2.905E+12
 4.4995     .313       .1968     .1956      .5972      130300     39.02      .1968
 41.69      40         0          0         13.916     .0239      .14        43
-----------------------------------------------------------------------------
129        1.3000     .1000      .1400      .1000      0.0000     .4319      4478.14
   .0590      .1943   56.6520    .596803    .05322     1.10314    .24262     2.949E+12
```

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 4.4995     .313       .4362      .4319      .6135      152100     33.03      .4359
 45.55      40.63      0          0          13.916     .0247      .14        42.28
-----------------------------------------------------------------------------------
138        1.2000     .1000      .1400      .1000      0.0000     .2515      4445.87
   .0440      .1788    56.4390    .586803    .04193     1.02108     .24087     2.938E+12
 4.206      .313       .2531      .2515      .6006      135600     40.15      .253
 43.19      40.47      0          0          13.009     .0246      .14        43.47
-----------------------------------------------------------------------------------
138        1.3000     .1000      .1400      .1000      0.0000     .4977      4613.46
   .1056      .2425    57.3140    .596803    .05322     1.10314     .24995     2.985E+12
 4.206      .313       .5035      .4977      .6168      158400     34.08      .5033
 46.12      41.15      0          0          13.009     .0255      .14        42.78
-----------------------------------------------------------------------------------
138        1.1000     .1000      .1400      .1000      0.0000     .0271      4278.29
  -.0176      .1152    55.5639    .576803    .03233     .937918     .23179     2.890E+12
 4.206      .313       .02752     .02705     .5825      114500     42.79      .0275
 37.48      39.79      0          0          13.009     .0236      .14        42.79
-----------------------------------------------------------------------------------
138        1.0000     .1500      .1300      .1500      0.0000     .0687      4567.67
  -.0246      .1079    55.4643    .545549    .03359     .814853     .24747     2.881E+12
 4.206      .313       .06933     .06866     .5868      118400     42.71      .06932
 38.48      39.71      0          0          14.009     .0252      .13        42.71
-----------------------------------------------------------------------------------
147        1.1000     .1000      .1400      .1000      0.0000     .0719      4391.39
   .0210      .1550    56.1118    .576803    .03233     .937918     .23792     2.920E+12
 3.9485     .313       .0725      .07188     .5858      118900     43.22      .07248
 38.74      40.22      0          0          12.212     .0243      .14        43.22
-----------------------------------------------------------------------------------
147        1.2000     .1000      .1400      .1000      0.0000     .3062      4570.46
   .0866      .2228    57.0439    .586803    .04193     1.02108     .24762     2.971E+12
 3.9485     .313       .3079      .3062      .6037      140800     41.04      .3079
 44.65      40.94      0          0          12.212     .0253      .14        43.94
-----------------------------------------------------------------------------------
147        1.0000     .1500      .1300      .1500      0.0000     .1145      4708.64
   .0298      .1641    56.2366    .545549    .03359     .814853     .25511     2.921E+12
 3.9485     .313       .1153      .1145      .5896      122900     43.31      .1153
 39.8       40.31      0          0          13.152     .026       .13        43.31
-----------------------------------------------------------------------------------
OPTIMUM WEIGHT IS:  4278  AT OR ABOVE LAST ENTRY
NUMBER IF OPTIMIZATION TRIALS PERFORMED IS:  12
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SST ISO - ISOGRID SHELL STRUCTURES

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FERMI      CONVENTIONAL ISOGRID ANALYSIS    ---  TRADES  ----
SECT: 1    ANG: 1     ALUM 5083-TO          ENGLISH UNITS
MACHINED/CAST FLANGED CROSS SECTION                  9 May 1991
SDC Vacuum Structure Ta= 5     SPEC. FILE: IFERMI
-----------------------------------------------------------------------------
Da$        Zo$        Zm$        Fa$        Ei$        Em$        Nl$        U$(1)
U$(2)      M$                    Bn$( )     St$        Ol$        O2$        O3$
Td         Bd         Poii       Faii       Fs         Ff(1)      Ff(2)      Fl_(1)
Fy         Fu         Nu         E          G          Rh         Ym         Wd
Wx         Wm         Tm         Bm         S1         Omii       Oxii       Odii
Cxii       Ssii       Fii        Bo         B5         B6         W5
Ad         P_(1)      Tf         Tf_(1)     Tf_(2)     Nx         Ei_req     V_mises$
Mii        P          Skinb$     Nro        Rc         R          RO         El
Et         Eb         Ew         CO         Cl         Cv         Ga         Rl
Keff       Kribax     Kribtor    Lf         Acone$     Cmin       B2min      Rib_step
Uf         Ug         Us         Gen$

 9 May 1   N          N          N          N          N          N          Y
N          ALUM 5083-TO          UFERMI1    RFERMI     Y          N          N
 .0100      .0500      2          0          22230          0          0      60000
 17000      39000      .330       1.02E+7    3.83E+6    .096       .010       .100
2.2000     1.0000      .0700      .4000      .1000     120        216         9
  0          4          0         .060       .060       .060        1
  .002     -30.0      100.0       0.0       100.0       175       0.0E+00    N
 107       -30        N          12         80         .09        .09        .02
 .004       .01        .004      .5         10.2       23.1       .61        .313
 1.38       1.4        1.4       40         N          .11        .095       0
 4          1          1         Y
=============================================================================
No         W          B          T          B2         C          Mg         Wf(1)
Mp(1)      Mp(2)      Ms         At         I          X          Tb_(1)     Ei
A          R2         Mh_min     Mhh_min    Gaa        Mg_shear   Mrib3781   Mha_min
Mgg        M_colx     M_coly     I_y        Knom       Wa_(1)     T2         Mribih
=============================================================================
120        1.0000     .4000      .2300      .0950      .1100      .2414      5551.19
 -1.7816     .0713    54.9615    1.07707    .04711     .822316     .31955     4.191E+12
 4.8369     .4655      .2802     .2487      .5644      143100     0           .2414
 23.81      20.39      0         0          9.1061     .0307      .23        23.39
-----------------------------------------------------------------------------
120        1.1000     .4000      .2300      .0950      .1100      .4926      5691.35
 -1.7616     .1081    55.4667    1.08657    .06021     .911281     .32762     4.229E+12
 4.8369     .4655      .544      .4926      .5824      167400     0           .4954
 24.03      20.61      0         0          9.1061     .0315      .23        23.61
-----------------------------------------------------------------------------
129        1.1000     .4500      .2200      .0950      .1100      .6210      5741.85
 -1.8171     .0063    54.0668    .949572    .06302     .899503     .33053     4.126E+12
 4.4995     .4905      .6878     .621       .5937      179700     0           .6327
 23.42      20         0         0          8.8558     .0317      .22        23
-----------------------------------------------------------------------------
129        1.2000     .4000      .2200      .0950      .1100      .8171      5816.00
 -1.8080     .0229    54.2955    .953572    .07417     .991031     .33480     4.143E+12
 4.4995     .4655      .9065     .8171      .6052      198900     0           .8428
 23.52      20.1       0         0          8.8558     .0321      .22        23.1
-----------------------------------------------------------------------------
129        1.0000     .4000      .2300      .0950      .1100      .3012      5670.64
 -1.7649     .1020    55.3827    1.00985    .04653     .818144     .32643     4.223E+12
```

4.4995	.4655	.3425	.307	.5684	149000	0	.3012
23.99	20.58	0	0	8.4708	.0313	.23	23.58
111	1.0000	.4000	.2300	.0950	.1100	.1801	5432.50
-1.7983	.0407	54.5403	1.00985	.04653	.818144	.31272	4.160E+12
5.2291	.4655	.2125	.1851	.56	137100	0	.1801
23.62	20.21	0	0	9.8444	.03	.23	23.21
111	1.1000	.4000	.2300	.0950	.1100	.4203	5561.05
-1.7798	.0747	55.0076	1.01935	.05953	.90642	.32012	4.195E+12
5.2291	.4655	.4657	.4203	.578	160200	0	.4203
23.83	20.41	0	0	9.8444	.0307	.23	23.41
102	1.1000	.4000	.2300	.0950	.1100	.3431	5431.68
-1.7980	.0413	54.5485	1.01935	.05953	.90642	.31267	4.160E+12
5.6905	.4655	.3854	.3458	.5732	152700	0	.3431
23.62	20.21	0	0	10.713	.03	.23	23.21
102	1.2000	.4000	.2300	.0950	.1100	.5837	5548.81
-1.7810	.0725	54.9779	1.02885	.07469	.993991	.31942	4.192E+12
5.6905	.4655	.6449	.5837	.5896	176300	0	.5929
23.81	20.4	0	0	10.713	.0307	.23	23.4
102	1.0000	.4000	.2300	.0950	.1100	.1137	5314.55
-1.8150	.0101	54.1191	1.00985	.04653	.818144	.30593	4.129E+12
5.6905	.4655	.1369	.1137	.5551	130800	0	.1173
23.44	20.03	0	0	10.713	.0294	.23	23.03
93	1.0000	.5000	.2300	.0950	.1100	.1648	5304.35
-1.8138	.0124	54.1512	1.02085	.05288	.809921	.30534	4.131E+12
6.2412	.5155	.1952	.1685	.5594	135500	0	.1648
23.45	20.04	0	0	11.75	.0293	.23	23.04
93	1.1000	.4000	.2300	.0950	.1100	.2639	5303.24
-1.8162	.0079	54.0894	1.01935	.05953	.90642	.30528	4.126E+12
6.2412	.4655	.303	.269	.5679	145000	0	.2639
23.42	20.01	0	0	11.75	.0293	.23	23.01
93	1.2000	.4000	.2300	.0950	.1100	.4925	5409.11
-1.8007	.0364	54.4810	1.02885	.07469	.993991	.31137	4.155E+12
6.2412	.4655	.5455	.4925	.5844	167300	0	.4975
23.59	20.18	0	0	11.75	.0299	.23	23.18
84	1.1000	.5000	.2300	.0950	.1100	.3048	5274.10
-1.8182	.0043	54.0398	1.03035	.06743	.897331	.30360	4.122E+12
6.9099	.5155	.3453	.3081	.5713	148900	0	.3048
23.4	19.99	0	0	13.009	.0291	.23	22.99
84	1.2000	.4000	.2300	.0950	.1100	.3982	5270.52
-1.8204	.0002	53.9840	1.02885	.07469	.993991	.30340	4.118E+12
6.9099	.4655	.4432	.3982	.5785	157900	0	.3992
23.37	19.97	0	0	13.009	.0291	.23	22.97
84	1.3000	.4000	.2300	.0950	.1100	.6237	5365.33
-1.8064	.0260	54.3376	1.03835	.09215	1.08087	.30885	4.144E+12
6.9099	.4655	.6903	.6237	.5936	180200	0	.6372
23.53	20.12	0	0	13.009	.0296	.23	23.12
75	1.2000	.5500	.2300	.0950	.1100	.4859	5266.38
-1.8183	.0040	54.0354	1.04535	.08903	.979169	.30316	4.122E+12

SST ISO - ISOGRID SHELL STRUCTURES

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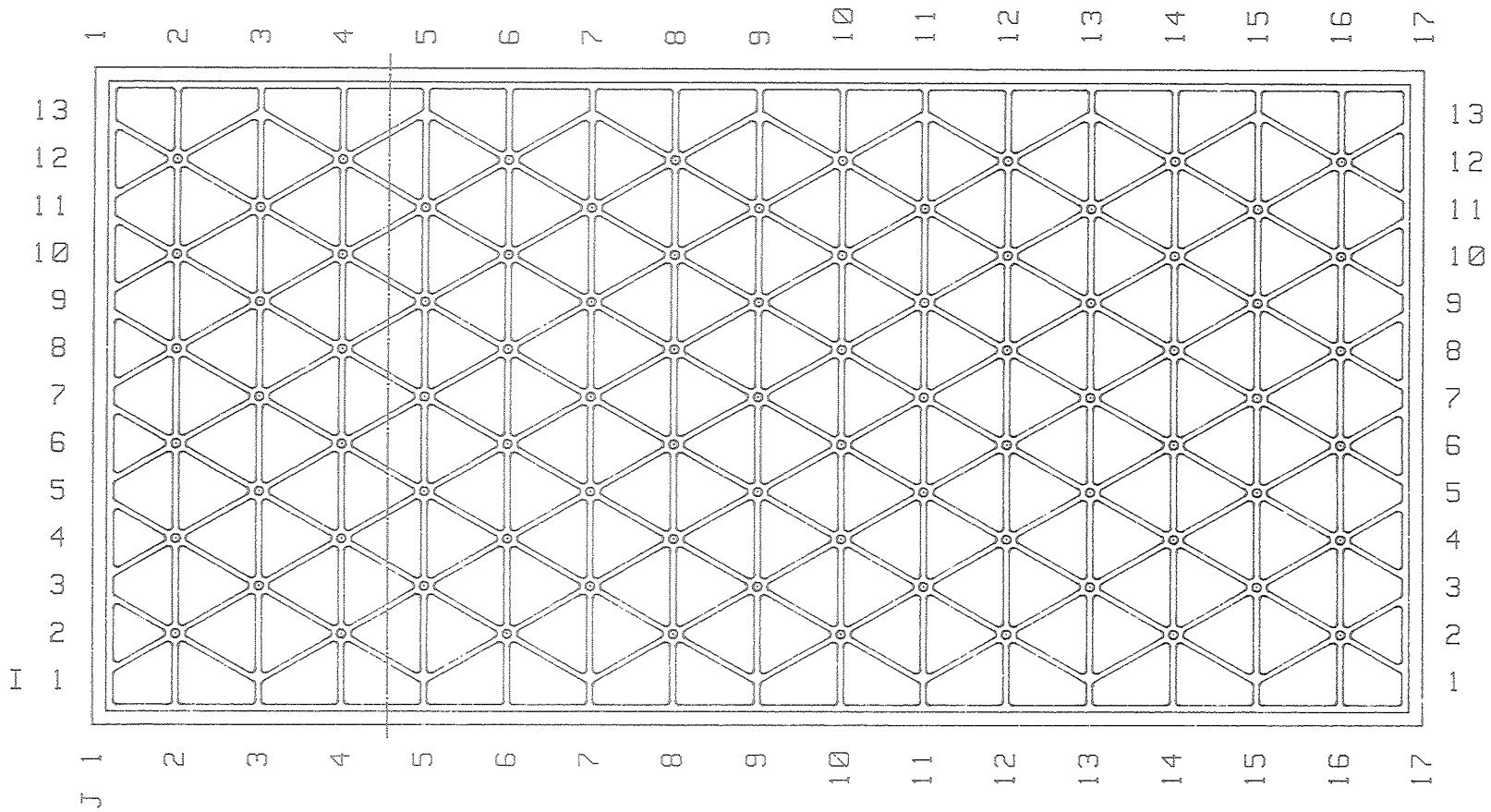
FERMI      CONVENTIONAL ISOGRID ANALYSIS    ---  TRADES  ----
SECT: 1    ANG: 1     ALUM 5083-T0          ENGLISH UNITS
MACHINED UNFLANGED CROSS SECTION            9 May 1991
SDC Vacuum Structure Ta= 5     SPEC. FILE: IFERMI
-----------------------------------------------------------------------------
Da$        Zo$        Zm$        Fa$        Ei$        Em$        N1$        U$(1)
U$(2)      M$                    Bn$( )     St$        O1$        O2$        O3$
Td         Bd         Poii       Faii       Fs         Ff(1)      Ff(2)      Fl_(1)
Fy         Fu         Nu         E          G          Rh         Ym         Wd
Wx         Wm         Tm         Bm         S1         Omii       Oxii       Odii
Cxii       Ssii       Fii        Bo         B5         B6         W5
Ad         P_(1)      Tf         Tf_(1)     Tf_(2)     Nx         Ei_req     V_mises$
Mii        P          Skinb$     Nro        Rc         R          R0         E1
Et         Eb         Ew         C0         C1         Cv         Ga         R1
Keff       Kribax     Kribtor    Lf         Acone$     Cmin       B2min      Rib_step
Uf         Ug         Us         Gen$

 9 May 1   N          N          N          N          N          N          Y
N          ALUM 5083-T0          UFERMI1    RFERMI     Y          N          N
 .0100      .0500      2          0          22230          0          0      60000
 17000      39000      .330       1.02E+7    3.83E+6    .096       .010       .100
2.2000     1.0000      .0700      .1000      .1000      120        216         9
  0          4          0         .060       .060       .060        1
  .002     -30.0      100.0       0.0       100.0       175       0.0E+00    N
 107       -30        N          12         80         0          .09        .02
 .004       .01        .004      .5         10.2       23.1       .61        .313
 1.67       1.4        1.4       40         N          0          .017       0
 4          1          1         Y
=============================================================================
No         W          B          T          B2         C          Mg         Wf(1)
Mp(1)      Mp(2)      Ms         At         I          X          Tb_(1)     Ei
A          R2         Mh_min     Mhh_min    Gaa        Mg_shear   Mrib3781   Mha_min
Mgg        M_colx     M_coly     I_y        Knom       Wa_(1)     T2         Mribih
=============================================================================
120        1.0000     .1500      .2300      .1500      0.0000     .0303      5575.86
 -1.7770     .0799    55.0785    1.08239    .03576     .831212     .32097     4.226E+12
 4.8369     .313       .04774    .03029     .5451      123600     23.44      .04038
 24.01      20.44      0          0         9.1061     .0308      .23        23.44
-----------------------------------------------------------------------------
120        1.1000     .1000      .2500      .1000      0.0000     .0132      5576.42
 -1.6664     .2829    57.8692    1.13567    .03439     .933391     .32101     4.435E+12
 4.8369     .313       .02803    .01319     .5382      122800     24.66      .02439
 25.25      21.66      0          0         8.3776     .0308      .25        24.66
-----------------------------------------------------------------------------
129        1.1000     .1000      .2400      .1000      0.0000     .0437      5510.95
 -1.7405     .1468    55.9981    1.02464    .03364     .933362     .31724     4.300E+12
 4.4995     .313       .06125    .04371     .5446      125300     23.85      .0544
 24.45      20.85      0          0         8.1178     .0305      .24        23.85
-----------------------------------------------------------------------------
129        1.2000     .1000      .2300      .1000      0.0000     .2584      5498.91
 -1.8064     .0259    54.3364    .959340    .04279     1.02384     .31654     4.182E+12
 4.4995     .313       .2977     .2649      .566       144700     23.12      .2584
 23.75      20.12      0          0         8.4708     .0304      .23        23.12
-----------------------------------------------------------------------------
129        1.3000     .1000      .2300      .1000      0.0000     .5024      5645.90
 -1.7860     .0633    54.8510    .969340    .05421     1.11277     .32500     4.224E+12
```

4.4995	.313	.5548	.5024	.5832	168400	23.35	.5058
24	20.35	0	0	8.4708	.0312	.23	23.35
138	1.2000	.1000	.2300	.1000	0.0000	.3153	5605.85
-1.7926	.0512	54.6846	.938234	.04261	1.02247	.32270	4.210E+12
4.206	.313	.357	.3203	.5698	150300	23.27	.3153
23.92	20.27	0	0	7.9183	.031	.23	23.27
138	1.3000	.1000	.2300	.1000	0.0000	.5687	5763.58
-1.7708	.0913	55.2351	.948234	.054	1.11116	.33178	4.255E+12
4.206	.313	.6269	.5687	.5869	175000	23.51	.575
24.19	20.51	0	0	7.9183	.0319	.23	23.51
138	1.1000	.1000	.2300	.1000	0.0000	.0764	5448.13
-1.8144	.0112	54.1342	.928234	.03305	.932945	.31362	4.165E+12
4.206	.313	.09697	.07636	.551	127700	23.03	.08392
23.65	20.03	0	0	7.9183	.0301	.23	23.03
138	1.0000	.1500	.2300	.1500	0.0000	.1303	5810.72
-1.7429	.1424	55.9384	.921827	.03451	.821843	.33449	4.294E+12
4.206	.313	.1529	.1303	.5527	133400	23.82	.137
24.41	20.82	0	0	7.9183	.0321	.23	23.82
147	1.1000	.1000	.2300	.1000	0.0000	.1244	5544.85
-1.8021	.0339	54.4465	.876943	.03267	.9299	.31919	4.191E+12
3.9485	.313	.1477	.1244	.5546	132200	23.17	.1289
23.8	20.17	0	0	7.4335	.0306	.23	23.17
147	1.2000	.1000	.2300	.1000	0.0000	.3710	5713.38
-1.7788	.0765	55.0328	.886943	.04218	1.01885	.32889	4.239E+12
3.9485	.313	.4151	.3744	.5733	155800	23.42	.371
24.09	20.42	0	0	7.4335	.0316	.23	23.42
147	1.0000	.1500	.2300	.1500	0.0000	.1810	5928.45
-1.7259	.1737	56.3684	.872673	.03408	.818286	.34127	4.328E+12
3.9485	.313	.2063	.181	.556	138100	24.01	.1837
24.61	21.01	0	0	7.4335	.0328	.23	24.01

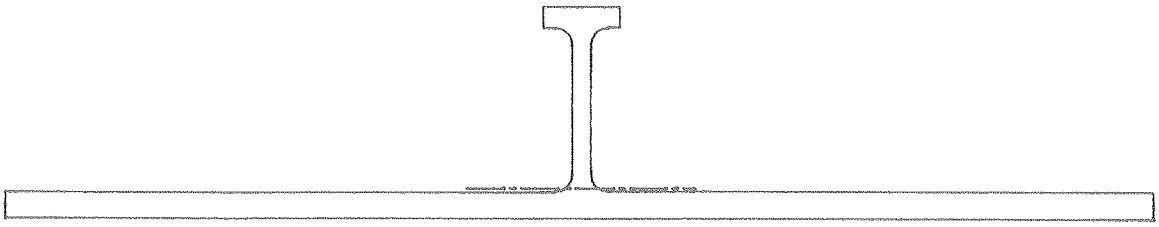
OPTIMUM WEIGHT IS: 5448 AT OR ABOVE LAST ENTRY
NUMBER IF OPTIMIZATION TRIALS PERFORMED IS: 12

SST-FLTISO FERMI



SDC Vacuum Structure

Radius= 15.27 Length= 48



SST ISO - SHELL STRUCTURE ANALYSIS

FERMI CONVENTIONAL ISOGRID ANALYSIS 9 May 1991

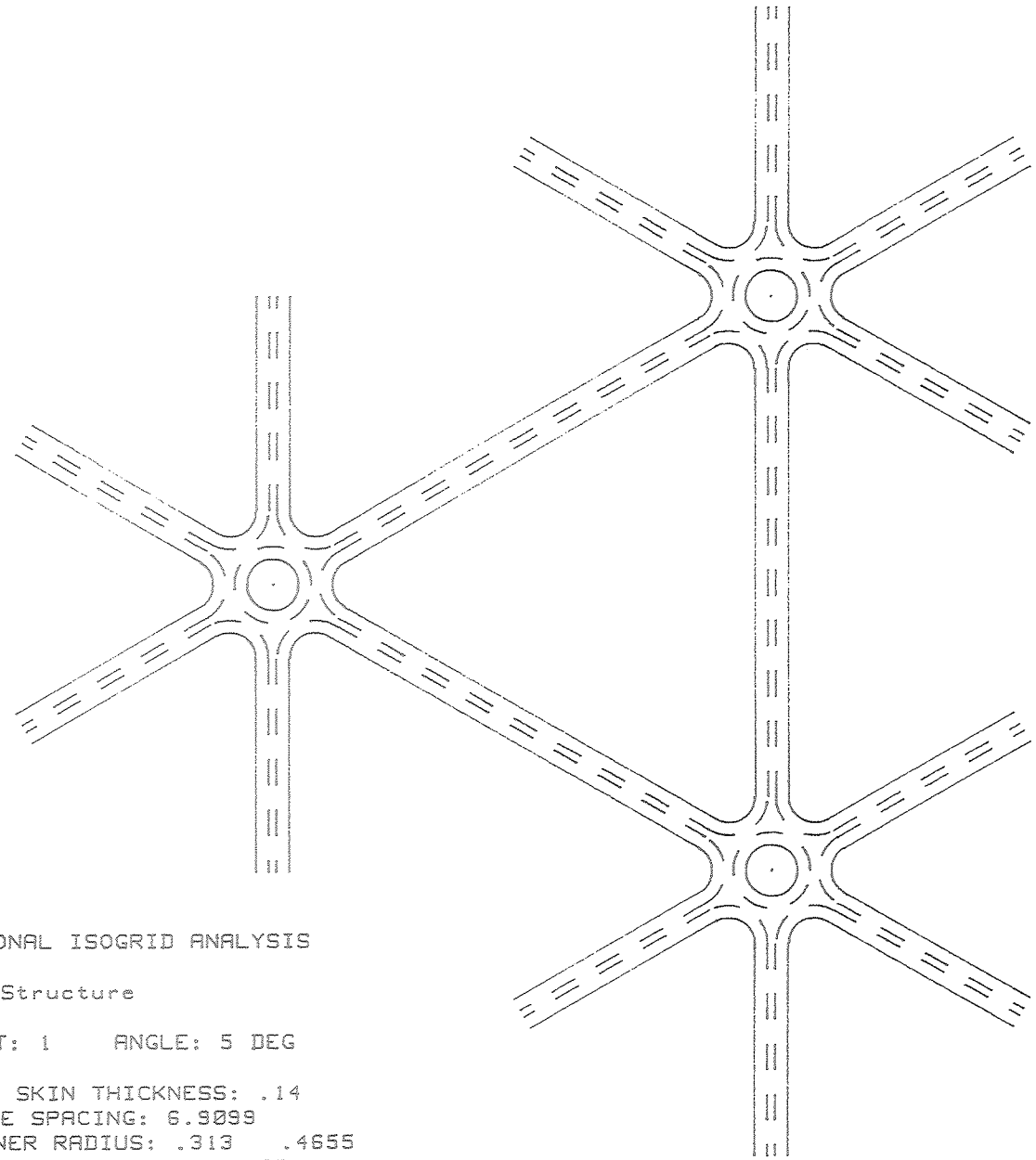
SDC Vacuum Structure

SECTION: 1 ELEMENT: 1 ANGLE: 5 DEG

ALUM 2219-T851 MACHINED/CAST FLANGED CROSS SECT.

PLOT SCALE: .92 ENGLISH UNITS

T SKIN THICKNESS	.14
W PLATE THICKNESS	1.1
B RIB WIDTH	.4
B2 WEB WIDTH	.095
C FLANGE THICKNESS, OUTER	.11
T2 FLANGE THICKNESS, AT SKIN	.14
SKIN FLANGE STEP	0
R FILLET RADIUS FLANGE	.09
R0 FILLET RADIUS SKIN	.09
R1 CORNER RADII, FLANGE	.313
R2 CORNER RADII, WEB	.4655
MAXIMUM SKIN WIDTH	5.98388
EFFECTIVE SKIN WIDTH	5.98388
I MOMENT OF INERTIA (X)	.06305
At TOTAL RIB CROSS SECTION AREA	.96946
Ar RIB CROSS SECTION AREA LESS SKIN	.1317
X CENTROIDAL AXIS REL. FLANGE OD	.94097
K NUMBER OF EFFECTIVE SKINS	21.371
Kx MAX. NUMBER OF EFFECTIVE SKINS	21.371

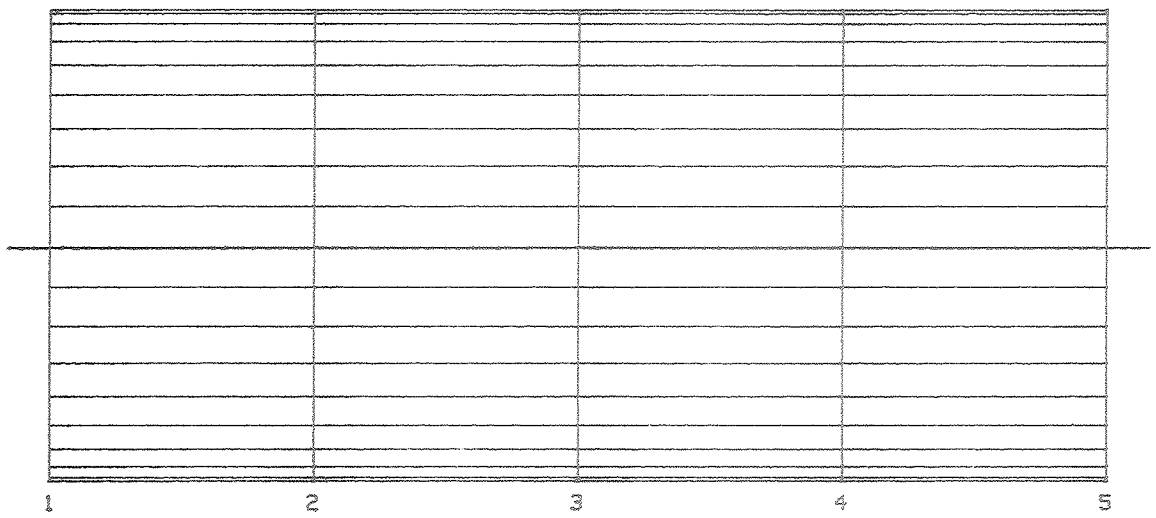


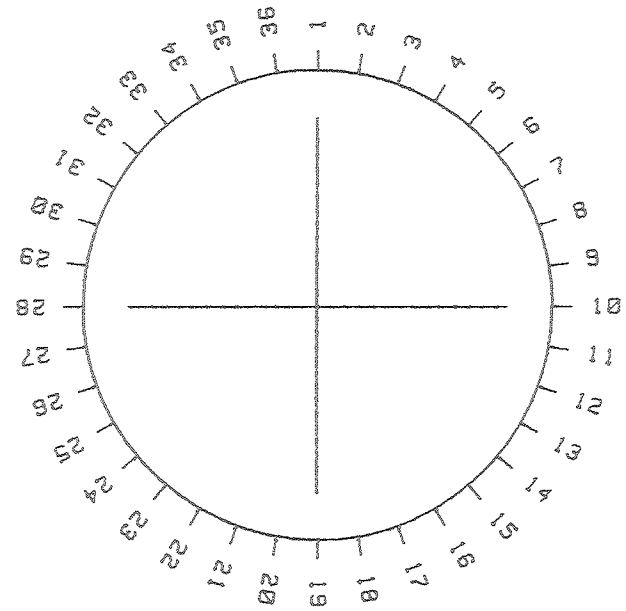
SST ISO FERMI CONVENTIONAL ISOGRID ANALYSIS

SDC Vacuum Structure

SECTION: 1 ELEMENT: 1 ANGLE: 5 DEG

PLATE THICKNESS: 1.1 SKIN THICKNESS: .14
RIB WIDTH: .4 NODE SPACING: 6.9099
PLOT SCALE: .52 RIB CORNER RADIUS: .313 .4655
WEB WIDTH: .095 UNDERCUT RADIUS: .4655





SST ISO ANALYSIS FERMI

SDC Vacuum Structure

ALUM 2219-T851 9 May 1991 PLOT SCALE: .0138

TOTAL LENGTH: 360 RADIUS: 80

PS▲A PS ASSOCIATES, INC.

5755 Oberlin Drive, Suite 300, San Diego, CA 92121
TEL (619) 453-3810 FAX (619) 453-9744

May 10, 1991

Mr. Chuck Grozis
Fermi National Accelerator Laboratory
P. O. Box 500
Batavia, Ill. 60510

Att.: Chuck Grozis

Dear Chuck,

I am pleased to submit the following ROM cost estimate for the production of a 4'x 8' isogrid test panel per attached SST generated rib cross section and flat pattern drawings.

Cost Estimate ---------- $24,900

Delivery: ---------- 18 to 20 weeks

Terms: ---------- 1% 10, net 30 days

F.O.B.: ---------- San Diego, CA

Sincerely,

Paul Slysh

Paul Slysh, President

PS.A PS ASSOCIATES, INC.

5755 Oberlin Drive, Suite 300, San Diego, CA 92121
TEL (619) 453-3810 FAX (619) 453-9744

May 9, 1991

5. Finite Element Results of the SDC Vacuum Structure

INTRODUCTION

Two finite element models were built of the SDC vacuum structure. Both models are identical except for rotational motion of the shell where it attaches to a rigid end plate. For the "free" model, no rotational constraint on the shell is applied in the circumferential direction where the shell attaches to the rigid end plate. For the "fixed" model, rotation of the shell is constrained to zero circumferential rotation where the shell attaches to the rigid end plate. Motion of the end plate is restricted only to axial motion caused by the vacuum loading.

Using symmetry boundary conditions the shell structure is modelled using 800 quadrilateral shell elements in a grid of 20 elements positioned uniformly in the circumferential direction by 40 elements positioned geometrically in the axial direction. Geometrical and material properties used in the analyses are given in Figure 1 where a schematic of the model is presented.

Loading on the vacuum shell consisted of a uniform pressure load of 30 psi applied both radially and on the annular bulkhead. The resulting axial loading was taken to be 88,000 pounds.

The sign convention for the membrane and bending stress resultants developed in the vacuum shell due to the pressure loading is given in Figure 2. Membrane stress resultants are positive when they cause tension. Positive bending stress resultants cause tension in the extreme isogrid flanges and compression in the isogrid skin.

RESULTS

Results for the "fixed" finite element model are presented in Figures 3 through 10. All results are plotted against x (cf. Figure 1), the shell axial coordinate.

The resulting radial displacement "w" is presented in Figure 3. Over most of the shell, the displacement is 0.11 inches. Due to bending, the maximum displacement is seen to be 0.115 inches about 20 inches from the bulkhead where it rapidly falls off to zero at the bulkhead. A finite element displacement plot of the vacuum shell is given in Figure 4.

The axial and circumferential bending stress resultants are given in Figure 5 and Figure 6, respectively. Over most of the shell the bending stress resultants are zero. The bending boundary layer is seen to extend about 20 inches from the bulkhead. The peak positive axial bending stress resultant is seen to be about 131 in-lb/in located 10 inches from the bulkhead, and the minimum axial bending stress resultant is -632 in-lb/in at the bulkhead. From Figure 6, the peak positive circumferential bending stress resultant is 39 in-lb/in located 10 inches from the bulkhead, and the minimum circumferential bending stress resultant is -190 in-lb/in at the bulkhead.

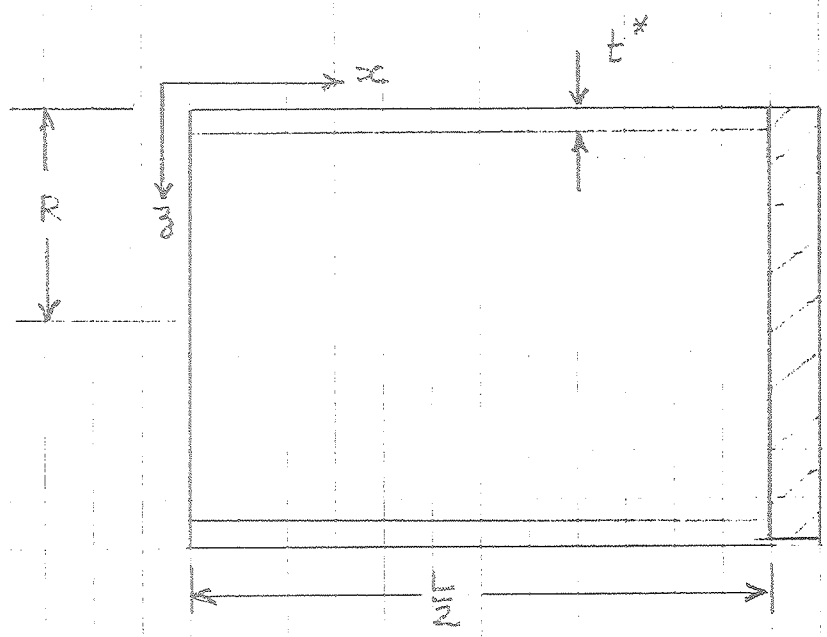
The axial and circumferential membrane stress resultants are given in Figure 7. As can be seen the axial membrane stress resultant is constant with a value of 174 lb/in. The circumferential membrane stress resultant is also constant except in the bending boundary layer where it dips slightly to -2,556 lb/in before going toward zero.

Using the axial membrane and bending stress resultants and the isogrid geometry, axial stresses in the isogrid skin and flange were computed and the results are presented in Figure 8. The minimum skin stress of -1,205 psi occurs 10 inches from the bulkhead. The maximum skin stress of -43 psi occurs at the bulkhead. The maximum flange stress of 104 psi occurs 10 inches from the bulkhead. The minimum flange stress of -6,343 psi occurs at the bulkhead.

In a similar manner, the circumferential membrane and bending stress resultants and isogrid geometry were used the compute the circumferential isogrid skin and flange stresses. These results are presented in Figure 9. The minimum skin stress of -14,773 psi occurs 20 inches from the bulkhead and the maximum skin stress of -12.8 psi occurs at the bulkhead. The minimum flange stress of 14,699 psi occurs 21 inches from the bulkhead. The maximum flange stress of -1,744 psi occurs at the bulkhead.

DISCUSSION

These results can be expected to give a good indication of the deformation and internal stresses experienced by the SDC vacuum shell during vacuum loading. As seen from these results, the shell-bulkhead interface and the resulting bending boundary layer cause significant variations in the stress values from the center portion of the shell. The modelling of the bulkhead in the finite element models is idealized, consequently, it should be expected that the bending boundary layer effects could be changed when an actual bulkhead (accounting for compliance effects and load path variations) is accurately modelled.



$L = 360''$

$R = 80''$

$t^* = 0.87''$

$E^x = 2 \times 10^6$ psi

FIGURE 1 SDC CYLINDER SHELL GEOMETRY

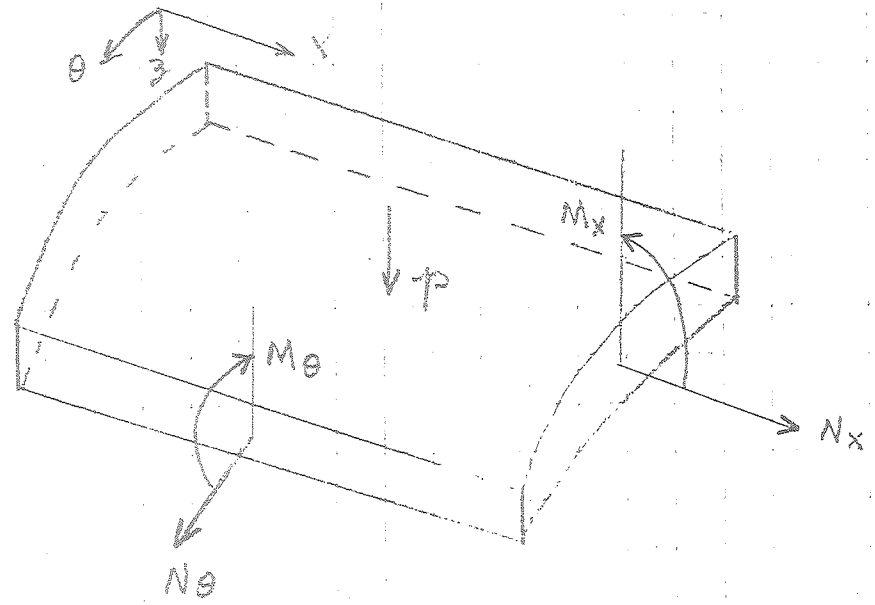


FIGURE 2. SIGN CONVENTION FOR MEMBRANE AND BENDING STRESS RESULTANTS.

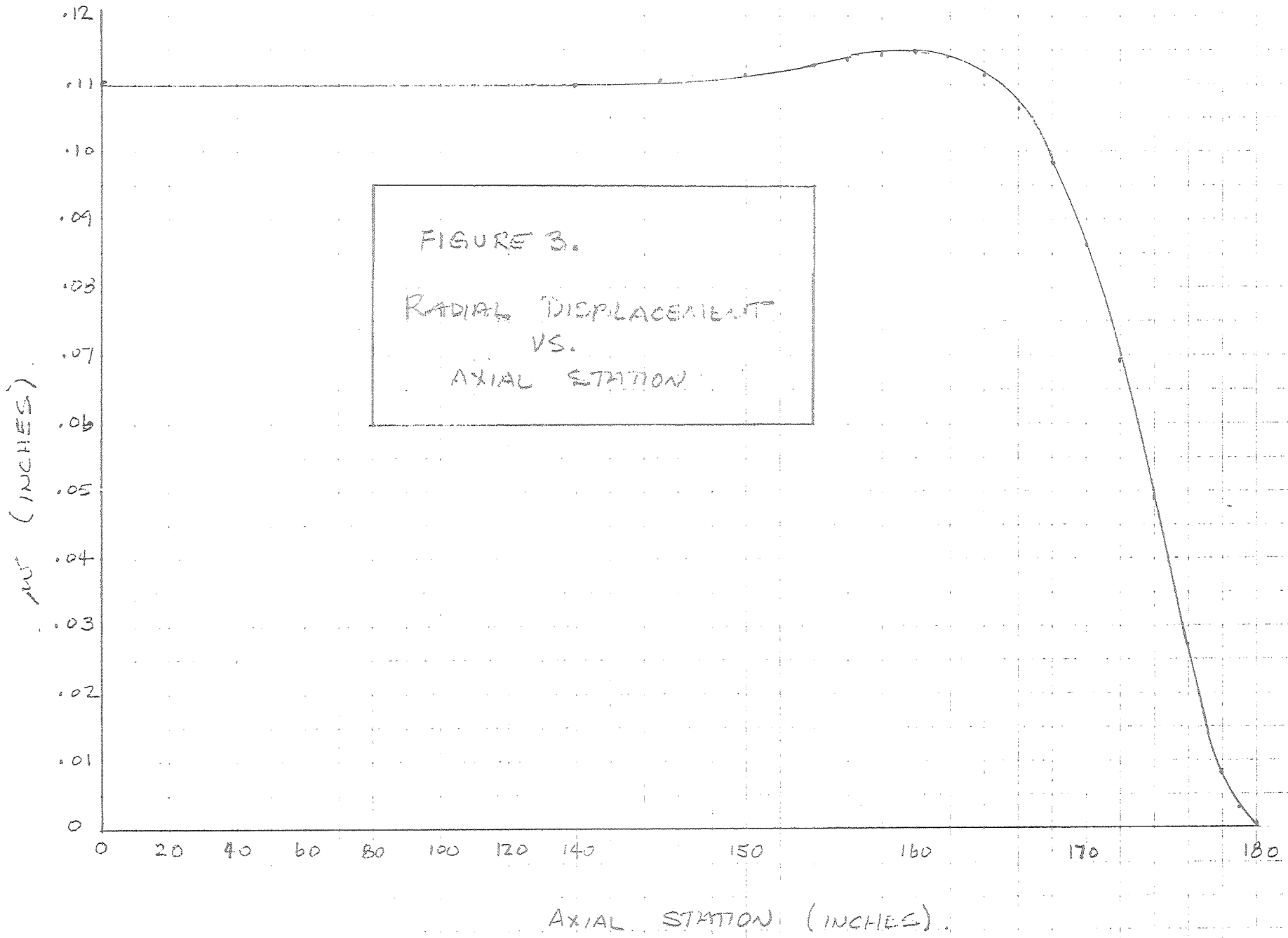


FIGURE 3.

RADIAL DISPLACEMENT VS. AXIAL STATION

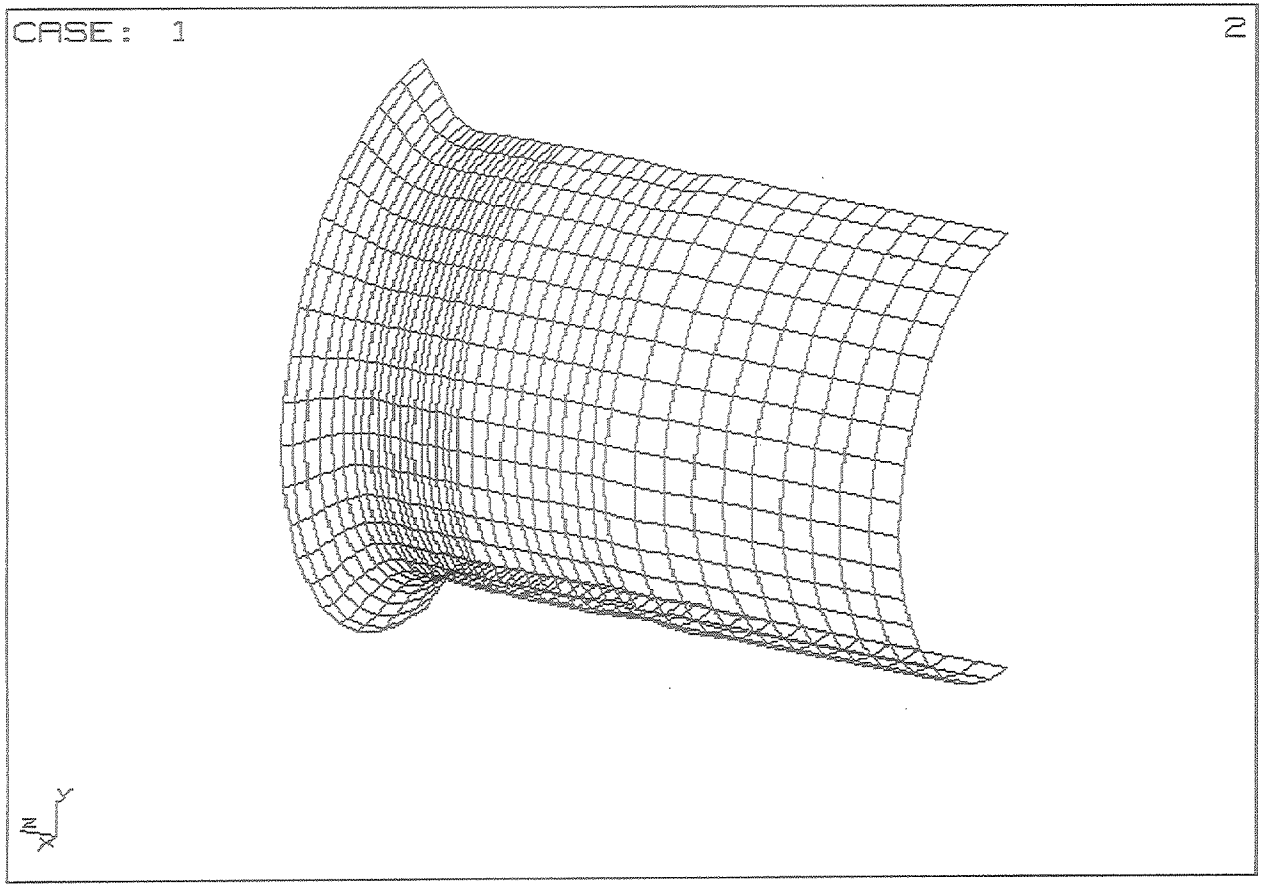


FIGURE 4.

FINITE ELEMENT RADIAL DISPLACEMENT PLOT.

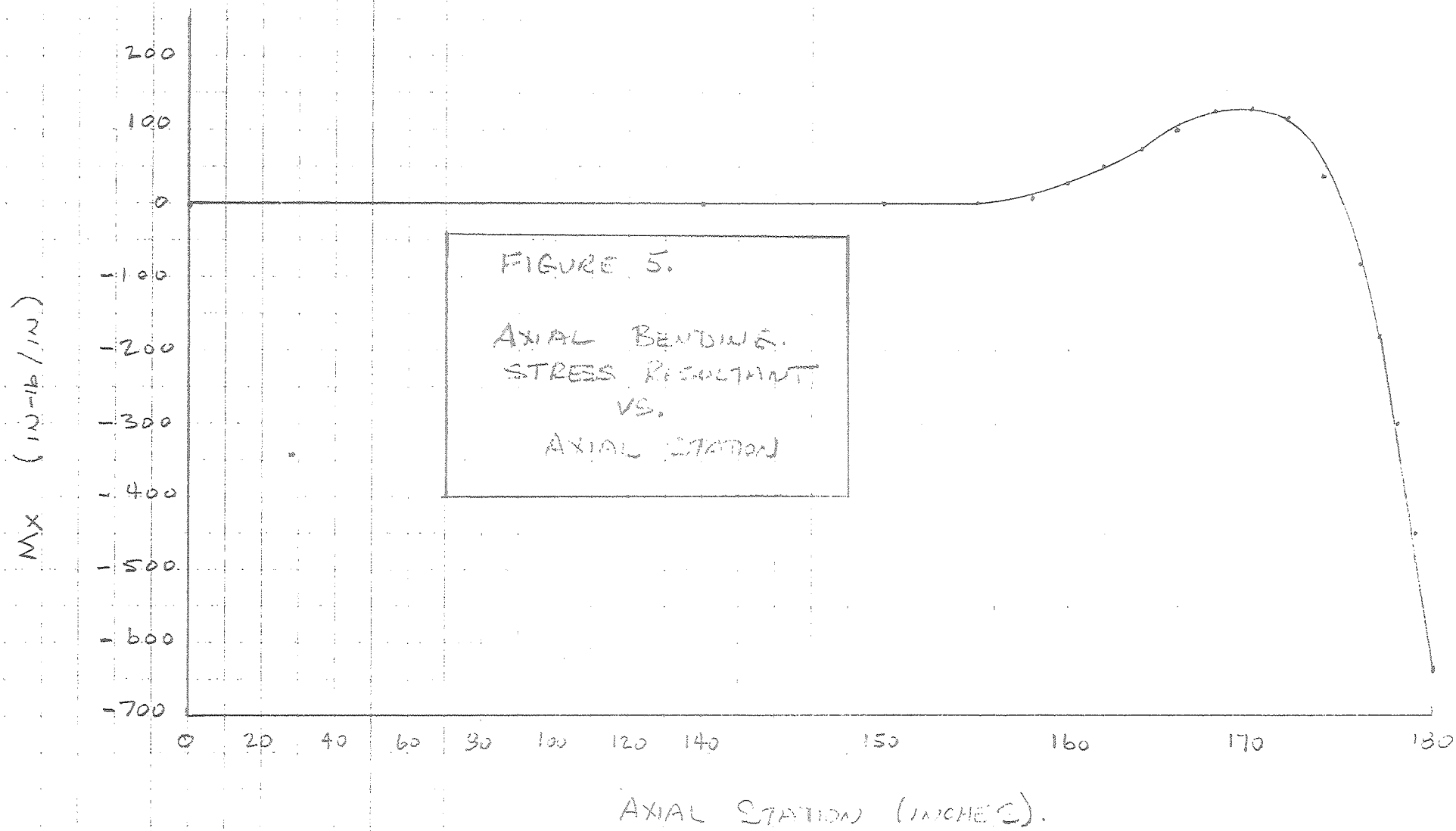


FIGURE 5.

AXIAL BENDING STRESS RESULTANT VS. AXIAL STATION

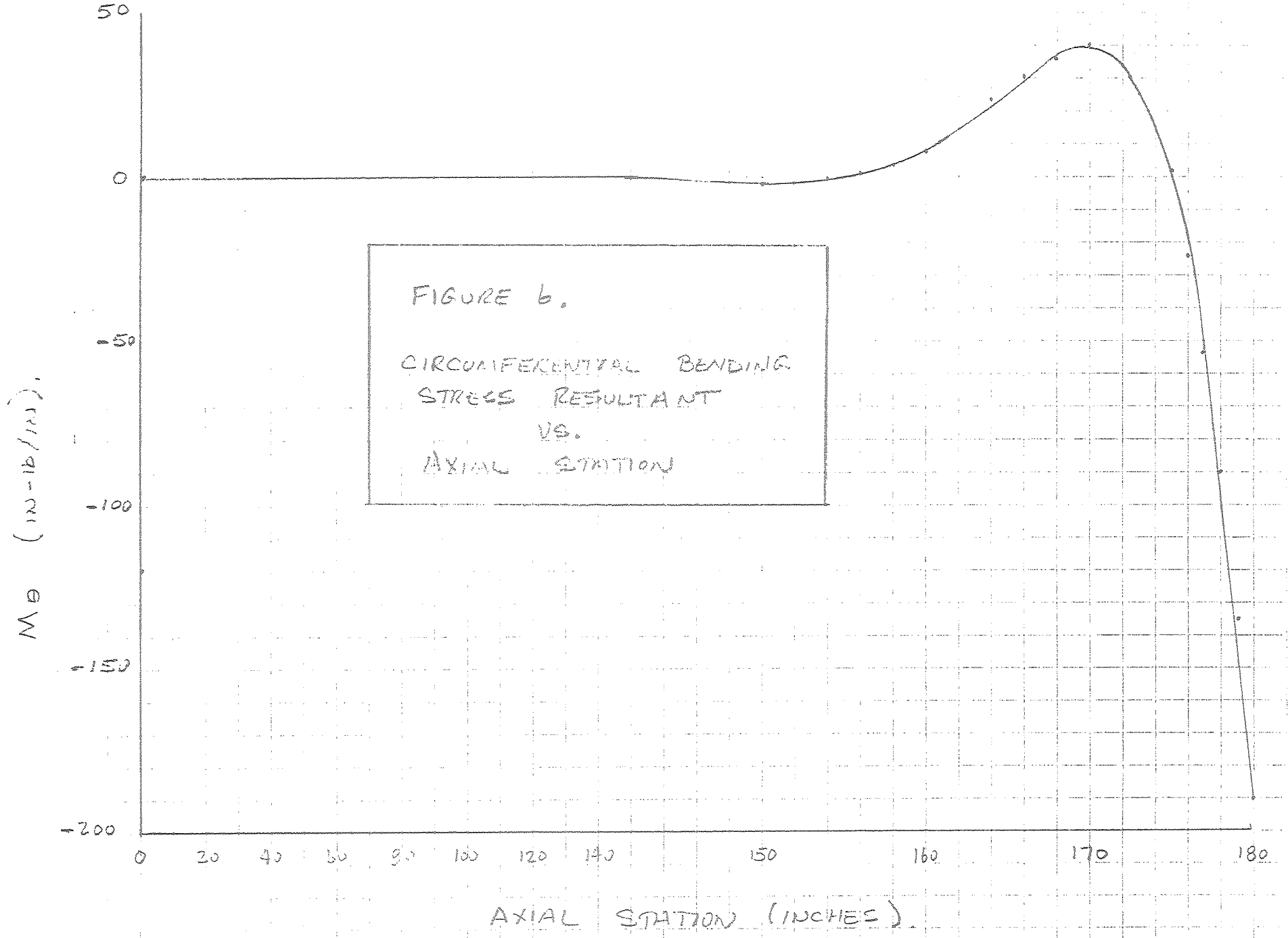


FIGURE 6.

CIRCUMFERENTIAL BENDING STRESS RESULTANT VS. AXIAL STATION

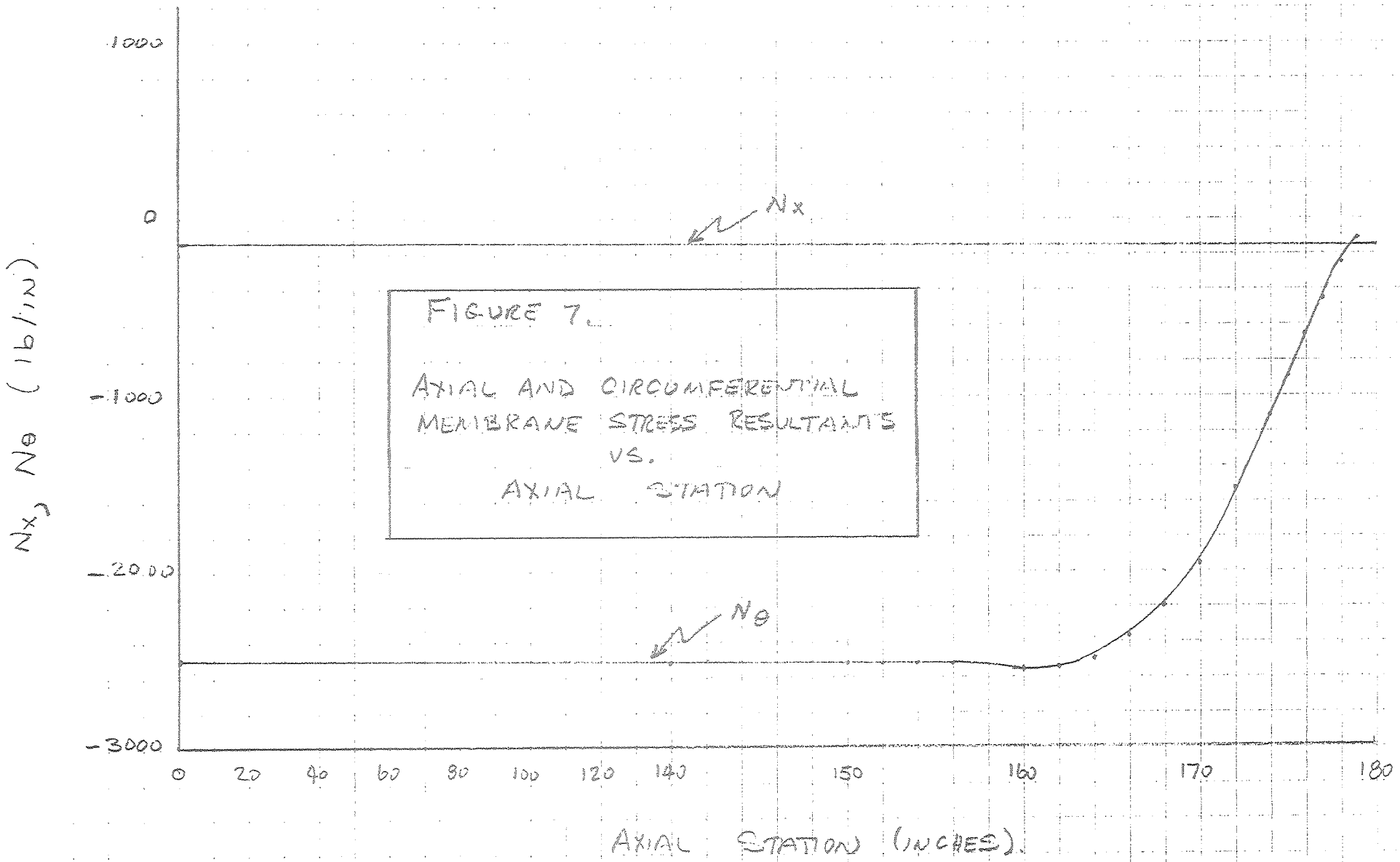


FIGURE 7.

AXIAL AND CIRCUMFERENTIAL MEMBRANE STRESS RESULTANTS VS. AXIAL STATION

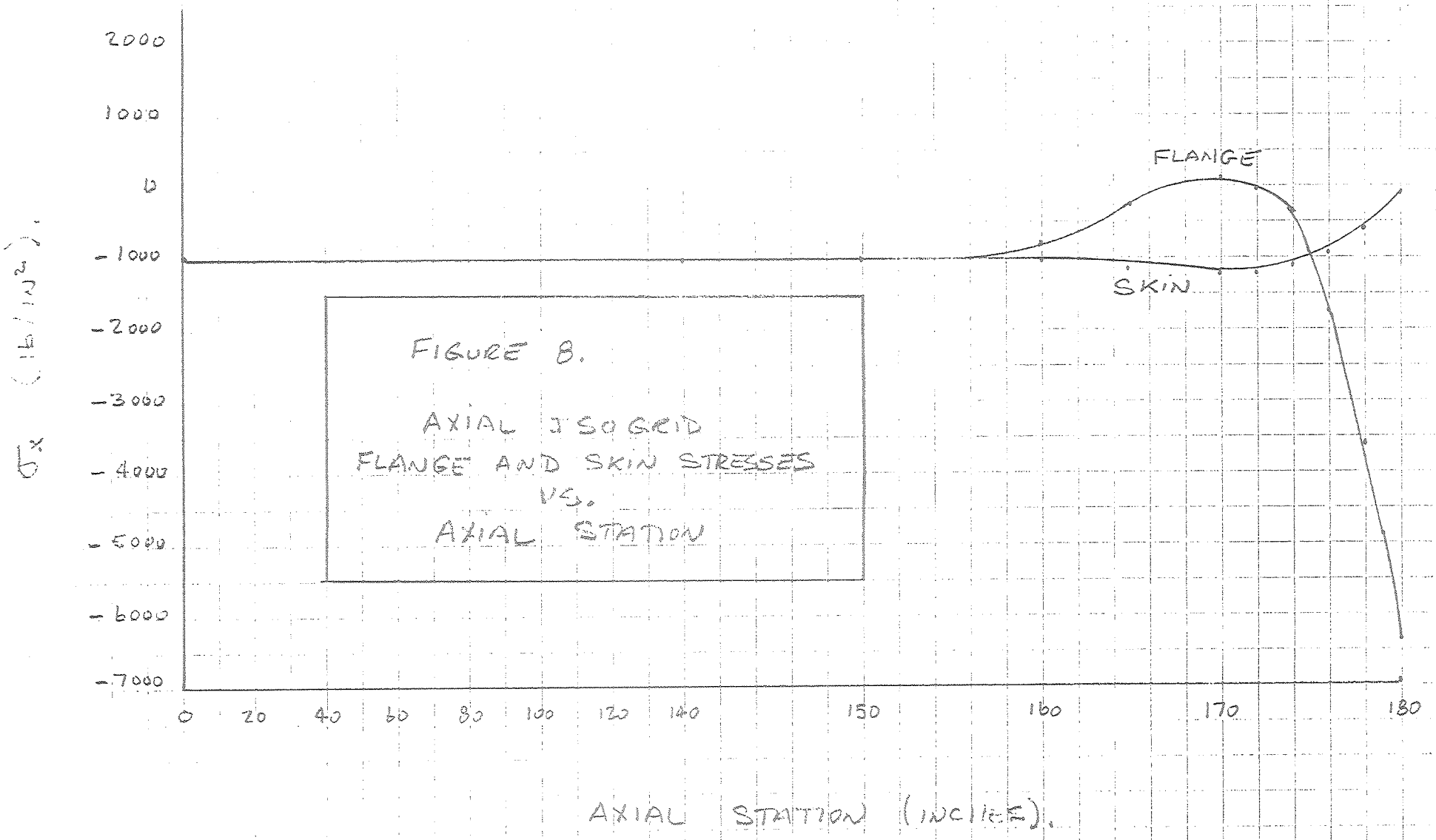


FIGURE 8.

AXIAL ISOGRID
FLANGE AND SKIN STRESSES
VS.
AXIAL STATION

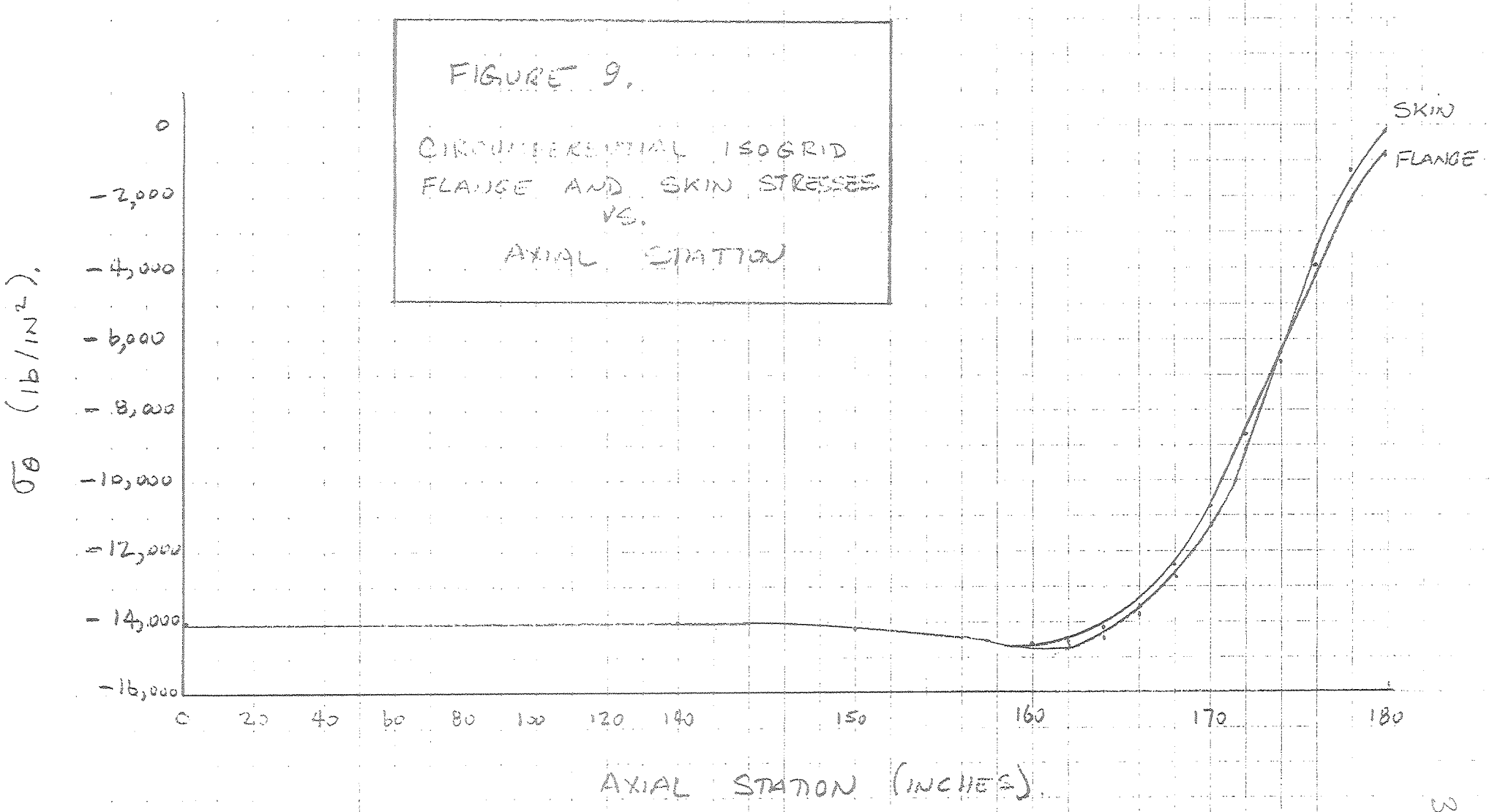


FIGURE 9.

CIRCUMFERENTIAL ISOGRID FLANGE AND SKIN STRESSES VS. AXIAL STATION

APPENDIX

37

PS.A PS ASSOCIATES, INC.

5755 Oberlin Drive, Suite 300, San Diego, CA 92121
(619) 453-3810 ▵ (FAX) (619) 453-9744

2/22/91

Dr. Ronald W. Fast
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

Dear Ron,

In accordance with our recent communications, PS.A is pleased to submit the following work statement and cost estimates.

Work Statement

Feasibility Study for SDC Vacuum Structure

1. Evaluate alternative, 360" long x 160" diameter, integral cylindrical shell structures including:

   a. Isogrid - flanged and unflanged.

   b. Waffle.

   c. Stiff-skin isogrid.

2. Primary study requirements:

   a. Satisfy 30 psi collapse.

   b. Minimize overall and local variations in aluminum thickness of outer shell.

   c. Satisfy a radial envelope of 2.5" which includes the overall stiffness of the structure, the sum of the shell thickness and forming tolerances, and pressure and dead weight induced deflections in the structure.

   d. Provide trades on basic mass properties and parameters defining overall and local variations in cylindrical shell thickness.

3. Ground Rules:

   a. Consider only aluminum.

   b. Analyses are to be performed for cylinders with both fixed and simple edge fixities.

   c. No penetrations in any part of the structure.

d. No thermal analysis to be performed.

e. Consider structural tailoring.

g. Allowable stress is not to exceed that permitted by Section VIII, Division 1 of the ASME Pressure Vessel Code for the aluminum alloy used.

h. The cylinder must have a safety factor of at least two on the Euler buckling caused by 15 psi induced axial loading.

i. All internally and externally generated suspension loads on the bulkheads will be fully equilbrated leaving no residual loads to be carried through the cylinder.

j. Shipping and handling loads on the cylinder are not to be considered at this time.

4. Optional Items:

a. Produce display samples that demonstrate manufacturing method feasibility.

b. Produce color shaded 3D graphics (using a feature solid modeler) that illustrate the structural features of the SDC dewar. At least four unique poster quality views on D size charts will be delivered.

Cost Estimates

Items 1, 2 and 3 using Versogrid Services ----------	$22,500
Period of performance for items 1, 2, and 3 --------	4 months
Item 4a ----------	$7,000 ROM
Item 4b ----------	$5,000 ROM
Period of performance for item 4b ----------	1 month after completion of items 1, 2, and 3.

Looking forward to working with you.

Sincerely yours,

Paul Slysh

Paul Slysh, President

cc:
Chuck Grozis
Dr. Lyle Swenson
Ang Lee