End Calorimeter Support Carriage Analysis

Engineering Note # 3740.224-EN-285

Issued: February 26, 1991

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END CALORIMETER SUPPORT CARRIAGE ANALYSIS

Kay Weber/Rick Luther

INTRODUCTION

The design of the EC carriage is based on the design of the CC carriage documented in D-0 Engineering Note 3740.215-EN-14. The non-symmetric weight distribution of the EC cryostat results in uneven loading of the arms of the EC carriage. The design load on each rear arm is 220,000 lb, while each front arm supports 40,000 lb. (The CC carriage design load was 200,000 lb on all four arms.) ANSYS finite element models were made representing various combinations of plate thicknesses in an attempt to balance the deflections of the arms. In the final design a 3/4" curved top plate is used with an additional 1.75" thick "doubler plate" incorporated into the rear arms. The bottom flanges are 2" and 3/4" for the rear and front arms, respectively. Web plates are 3/4" for all arms. The carriage bottom plate is 2" thick, and other details are similar to the CC design.

SUMMARY OF RESULTS

Table 1 presents stress levels at various locations in the carriage along with allowable values taken from the AISC Specification for Structural Steel. Locations are shown in Figure 1. All calculations are contained in Appendix A.

WELDS

All welds in the structure are full-thickness groove welds or fillet welds made with E308/E309 filler metal having a minimum ultimate strength of 80 ksi. Fillet weld sizing calculations are included in Appendix A.

DEFLECTIONS

Table 2 gives deflections of the arms of the carriage for various combinations of plate thicknesses as determined by finite element analysis. Deflections of both carriages were measured during load tests and are documented in Engineering Note 3740.224-EN-282.

FINITE ELEMENT ANALYSIS

The finite element analysis used to size components of the carriages is described in Appendix B.

TABLE 1
STRESS SUMMARY

Location	Stress (ksi)	Allowable (ksi)
Rear Arms		
Section A-A	fb=8.0	Fb=19.8
B-B	fb=3.8	Fb=19.8
B5-B5	fb=12.9	Fb=19.8
C-C	fb=11.3	Fb=19.8
D-D	fb=11.2	Fb=18.0
E-E	ft=17.0	Ft=18.0
	fc=13.9	Fc=18.0
Front Arms		
Section A-A	fb=2.4	Fb=19.8
B-B	fb=3.8	Fb=19.8
B5-B5	fb=5.6	Fb=19.8
C-C	fb=4.5	Fb=19.8
D-D	fb=5.1	Fb=18.0
E-E	ft=11.0	Ft=18.0
	fc=2.7	Fc=18.0
Stanchion Support		
Plate Bending	fb=12.9	Fb=22.5
Gusset Bending	fb=11.7	Fb=19.8
Support Bracket		
Web Bending	fb=12.6	Fb=19.8
Shear	fs=2.4	Fs=12.0
Plate Bending	fb=13.5	Fb=22.5

ALLOWABLE STRESSES

Allowable stresses for the carriage design were taken from Section 1.5 of the AISC Specification for Structural Steel for Buildings. The carriages are constructed of type 304 stainless steel having a minimum yield strength of 30 ksi and a minimum ultimate strength of 75 ksi. The applicable allowable stresses are:

Bending in a compact section	$Fb = .66F_y = 19.8 \text{ ksi}$
Bending in a general section	$Fb = .60F_y = 18.0$
Bending in a solid rect.angle	$Fb = .75F_y = 22.5$
Tension	$Ft = .60F_y = 18.0$
Compression (no buckling)	$Fc = .60F_y = 18.0$
Shear	$Fs = .40F_y = 12.0$

1)

ANSYS 4.3A
AUG 9 1989
10 50 55
PLOT NO. 3
PREP7 ELEMENTS

ZV = 1
DIST = 85.626
YF = 1.001
ZF = -30.063
PRECISE HIDDEN

Figure 1

EC CRADLE

w

TABLE 2
EC CRADLE DEFLECTIONS

	CENTER OF FRONT ARM	CENTER OF REAR ARM
1.5" TOP PLATE 2" ANGLE PLATES	-.05728	-.2875
1" FRONT, 2" REAR TOP PLATE, 2" ANGLE PLATES	-.06337	-.2684
1" FRONT, 2" REAR TOP PLATE, 1" FRONT ANGLE PLATE	-.07431	-.2687
1" FRONT, 2.5" REAR TOP PLATE, .75" FRONT ANGLE PLATE	-.07867	-.2521
.75" FRONT, 2.5" REAR TOP PLATE, .75" FRONT ANGLE PLATE	-.08629	-.2537

1. FOR SECTION - SEE 3.1.
2. FOR MATERIALS - SEE 3.2.
3. FOR INSTALLATION PROCEDURES - SEE 3.3.
4. FOR MAINTENANCE PROCEDURES - SEE 3.4.
5. FOR REMOVAL PROCEDURES - SEE 3.5.
6. FOR SAFETY PROCEDURES - SEE 3.6.
7. FOR QUALITY CONTROL PROCEDURES - SEE 3.7.
8. FOR RECORDS - SEE 3.8.
9. FOR TRAINING - SEE 3.9.
10. FOR INSPECTION - SEE 3.10.
11. FOR TESTING - SEE 3.11.
12. FOR EVALUATION - SEE 3.12.
13. FOR REPORTING - SEE 3.13.
14. FOR APPROVAL - SEE 3.14.
15. FOR SIGNATURE - SEE 3.15.
16. FOR DATE - SEE 3.16.
17. FOR PROJECT - SEE 3.17.
18. FOR LOCATION - SEE 3.18.
19. FOR DRAWING - SEE 3.19.
20. FOR REVISION - SEE 3.20.

[illegible]DO DETECTOR
END CALORIMETER SUPPORT
CALORIMETER SUPPORT

DATE	CLASS	STATUS	REMARKS
10/10/19	10/10/19	10/10/19	10/10/19

3740.220-4E-2234J2 5

17 PM 1-DECA 4.0	WATER WIND: 11.0
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APPENDIX A

STRESS CALCULATIONS

LOADS FOR EC CRADLE DESIGN

	<u>REAR STANCHIONS</u>	<u>FRONT STANCHIONS</u>
MODULES	158400	21700
ARGON	45650	6225
INNER VESSEL	7350	7425
OUTER VESSEL	7350	7425
	<u>218750</u>	<u>42775</u>
	<u>USE 220000 #/STANCHION</u>	<u>45000 #/STANCHION</u>

1)

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EC CRADLE

ANSYS 4.3A
AUG 9 1989
10 50 55
PLOT NO. 3
PREP7 ELEMENTS

ZV = 1
DIST=85.626
YF = 1.001
ZF = -30.063
PRECISE HIDDEN

A-2

SECTION A-A

	A	y	Ay	Ad	I
1	21.	11.75	246.75	743.5	3.9
2	13.5	6.5	87.75	6.6	91.1
3	28.	1.	28.	645.1	9.3
	62.5		362.5	1395.2	104.3

$$y=5.8 \quad I=1500 \quad S_b=258.8 \quad St=223.8$$

$$M = Fd = 178 * 9.97 = 1775$$

$$fb = M / S_b = 1775 / 223.8 = 7.93$$

$$fa = Fx / A = 130 / 62.5 = 2.08$$

$$fs = P / (d * t) = 178 / (12.5 * 1.5) = 9.5$$

	A	y	Ay	Ad	I
1	21.	10.5	220.5	325.6	3.9
2	13.5	5.25	70.875	23.16	91.1
3	10.5	.375	3.93	536.1	.49
	45.		295.3	884.7	96.3

$$y=6.56 \quad I=981 \quad S_b=149.6 \quad St=209.$$

$$M = 36.5 * 9.97 = 364$$

$$fb = 364 / 149.6 = 2.43$$

$$fa = 36.5 / 45 = .589$$

$$fs = 36.5 / (12.5 * 1.5) = 1.95$$

SECTION B-B

	A	y	Ay	Ad	I		A	y	Ay	Ad	I
1	21.	15.	315.	1386.	3.9	1	21.	16.43	345.	968.	3.9
2	17.63	8.3	147.6	40.	401.	2	17.63	8.3	146.4	31.4	401.
3	35.	1.25	43.75	1108.	18.3	3	13.02	.465	6.05	1096.	.938
	73.63		506.4	2534.	423.		51.6		497.5	2095.	406.

$$y=6.88 \quad I=2957 \quad S_b=249 \quad S_t=430 \quad y=9.64 \quad I=2501 \quad S_b=260 \quad S_t=146.$$

$$M = F * d = 220 * (73.35 - 61.016) = 2714. \quad M = 45 * (73.35 - 61.016) = 555.$$

$$f_b = M / S_b = 2714 / 249 = 10.9$$

$$f_b = 555 / 146 = 3.8$$

$$f_s = F / (d * t) = 220 / (15.75 * 1.5) = 9.31 \quad f_s = 45 / (15.75 * 1.5) = 1.9$$

SECTION B1-B1

	A	y	Ay	Ad	I
1	39.6	16.7	659.7	2287.	26.4
2	19.13	7.63	145.8	39.4	259.
3	35.	1.25	43.75	2135.	18.2
	93.73		849.25	4462.	303.6

$$y=9.06 \quad I=4766 \quad S_b=526. \quad S_t=528.$$

$$M = F * d = 220 * (73.35-50) = 5135$$

$$fb = M / S_b = 5135 / 526. = 9.76$$

	A	y	Ay	Ad	I
1	11.9	15.68	186.5	1185.	.716
2	19.13	7.625	145.8	71.	259.
3	35.	1.25	43.75	692.	18.2
	66.		376.	1948.	278.

$$y=5.7 \quad I=2226 \quad S_b=391 \quad S_t=180.$$

$$M = 45 * (73.35 - 50) = 1050.3$$

$$fb = 1050 / 180 = 5.8$$

SECTION B2-B2

	A	y	Ay	Ad	I
1	38.5	17.63	678.6	2562.	24.3
2	20.63	8.13	167.6	37.2	325.
3	35.	1.25	43.75	2363.	18.2
	94.		889.9	4962.	367.5

$$y=9.47 \quad I=5330 \quad S_b=563 \quad S_t=559$$

$$M = F * d = 220 * (73.35 - 45) = 6237$$

$$f_b = M / S_b = 6237 / 559 = 11.16$$

	A	y	Ay	Ad	I
1	11.6	16.67	193.4	1223.	.67
2	20.6	9.375	193.	182.	325.
3	35.	1.25	43.75	929.	18.2
	67.2		430.1	2334.	344.

$$y=6.4 \quad I=2678 \quad S_b=418 \quad S_t=251.$$

$$M = 45 * (73.35 - 45) = 1275.$$

$$f_b = 1275 / 251 = 5.08$$

SECTION B3-B3

	A	y	Ay	Ad	I
1	48.9	15.96	652.4	2852.	29.
2	18.	8.5	153.	.56	216.
3	35.	1.25	43.75	1750.	18.2
	102.		849.	4604.	263.

$$y=8.32 \quad I=5022 \quad S_b=604 \quad St=552$$

$$M = F * d = 220 * (73.35-55) = 4037$$

$$fb = M / S_b = 4037 / 552 = 7.3$$

	A	y	Ay	Ad	I
1	12.25	14.94	183.	1018.	.782
2	18.	8.5	153.	129.	216.
3	35.	1.25	43.75	731.	18.2
	65.25		379.75	1878.	235.

$$y=5.82 \quad I=2113 \quad S_b=363 \quad St=221.$$

$$M = 45 * (73.35 - 55) = 825.75.$$

$$fb = 825.75 / 221 = 3.74$$

SECTION B4-B4

	A	y	Ay	Ad	I
1	37.8	18.85	712.5	2766.	22.9
2	22.5	10.	225.	1.98	422.
3	35.	1.25	43.75	2363.	18.2
	95.3		981.25	5632.	463.

$$y=10.296 \quad I=6095 \quad S_b=592 \quad S_t=615$$

$$M = F * d = 220 * (73.35 - 40) = 7337$$

$$f_b = M / S_b = 7337 / 592 = 12.4$$

	A	y	Ay	Ad	I
1	11.3	17.9	202.5	1381.	.615
2	22.5	10.	225.	223.8	422.
3	35.	1.25	43.75	929.	18.2
	68.8		471	2700.8	440.8

$$y=6.85 \quad I=3142 \quad S_b=459 \quad S_t=274$$

$$M = 45 * (73.35 - 40) = 1500.75$$

$$f_b = 1501 / 274 = 5.5$$

SECTION B5-B5

	A	y	Ay	Ad	I
1	37.24	19.83	738.5	3072.6	21.96
2	24.	10.5	252.	1.459	512.
3	35.	1.25	43.75	3156.	18.2
	96.24		1034.	6230.	552.

$$y=10.75 \quad I=6782 \quad S_b=631 \quad St=651$$

$$M = F * d = 220 * (73.35 - 36.43) = 8122.4$$

$$fb = M / S_b = 8122.4 / 631 = 12.87$$

	A	y	Ay	Ad	I
1	11.17	18.9	211.	1524.	.593
2	24.	10.5	252.	258.2	512.
3	35.	1.25	43.75	1247.	18.2
	70.172		506.9	3029.6	530.8

$$y=7.22 \quad I=3560 \quad S_b=493 \quad St=295.$$

$$M = 45 * (73.35 - 36.43) = 1661.4$$

$$fb = 1661.4 / 295 = 5.63$$

SECTION C-C

	A	y	Ay	Ad	I
1	46.8	23.1	1081.	4708.	26.36
2	29.7	11.9	353.4	40.7	970.
3	36.	1.	36.	5245.	12.
	112.5		1470.4	9993.	1008.

$$y=13.07 \quad I=11001 \quad S_b=841.7 \quad St=970.9$$

$$M = F * d = 220 * (73.35-30) = 9535$$

$$fb = M / S_b = 9535 / 841.7 = 11.33$$

	A	y	Ay	Ad	I
1	14.0	22.19	311.5	2519.	.7118
2	29.7	11.9	353.4	286.5	970.
3	36.	1.	36.	2187.	12.
	79.7		700.9	4992.5	983.

$$y=8.79 \quad I=5976 \quad S_b=769.8 \quad St=433.4$$

$$M = 45 * (73.35 - 30) = 1950.$$

$$fb = 1950 / 433 = 4.5$$

SECTION D-DREAR FRONT

	A	y	Ay	Ad	I
1	130.	18.94	2462.	7978.	67.7
2	8.63	14.813	127.76	118.6	27.76
3	104.	1.	104.	10617.	34.67
	242.6		2693.	18713.	130.

$$y = 11.1 \quad I = 18843 \quad S_b = 1697 \quad S_t = 2075$$

$$M = F * d = 220 * (73.35 - 45) = 6237$$

$$f_b = M / S_b = 6237 / 559 = 11.16$$

	A	y	Ay	Ad	I
1	18.	19.813	356.6	2719.	.844
2	11.25	15.688	176.5	750.	52.73
3	48.	1.	48.	2042.	16.
	77.25		581.	5511.	69.57

$$y = 7.52 \quad I = 5581 \quad S_b = 742 \quad S_t = 441.$$

$$M = 45 * (73.35 - 45) = 1275.$$

$$f_b = 1275 / 251 = 5.08$$

SECTION E-E

$$M = 220 * (73.34 - 21.875) = 11322$$

$$T = 11322 / 17.75 = 638$$

$$f_t = T / (t * L) = 638 / (2.5 * 15) = 17$$

$$f_c = T / (t * L) = 638 / 2 * 23 = 13.9$$

$$M = 45 * (73.34 - 21.875) = 2316$$

$$T = 316 / 17.75 = 124$$

$$f_t = 124 / (.75 * 15) = 11$$

$$f_c = 124 / (2 * 23) = 2.7$$

STANCHION SUPPORT PLATE

AREA OF LOAD = 13" CIRCLE

$$P = F / A = 220 / (3.14 * 6.5 * 6.5) = 1.66$$

IF THE LOAD IS CENTERED OVER THE GUSSET PLATE, HALF THE LOAD IS OVER THE PLATE AREA BETWEEN THE ANGLES PLATE AND GUSSET PLATE

PER ROARK AND YOUNG, TABLE 26, CASE 1a
FOR A PLATE 10.5 X 7:

$$a/b = 10.5/7 = 1.5 \quad B = .7116$$

$$fb = (B * (P/2) * b * b) / (t * t) = (.7116 * .83 * 7 * 7) / (1.5 * 1.5) = 12.9$$

STANCHION GUSSET PLATE

	A	y	Ay	Ad	I
1	10.5	5.25	55.125	14.5	1.969
2	6.75	2.25	15.188	22.5	11.4

17.25 70.313 37. 13.36

$y = 4.076$ $I = 50.36$ $S_b = 12.4$ $S_t = 26.2$

$$w = 110/10.5 = 10.5$$

$$M = (w * L * L) / 8 = (10.5 * 10.5 * 10.5) / 8 = 144$$

$$f_b = M / S = 144 / 12.4 = 11.7$$

SUPPORT

1	21.	19.25	414.75	1442	85.75
2	65.	8.13	528.13	524	86.67
<hr/>					
	86.		942.88	1966.	172.

$$y=10.96 \quad I=2138. \quad S_b=195. \quad S_t=174.$$

Max. Moment occurs when load is at the edge ($l=10$)

$$M_{\max} = 10 \times 220 = 2200$$

$$f_b = 2200 / 174 = 12.6$$

BEARING PLATE

Per Roark, Table 26 #7f

$$fb = (B2 * w * b) / (t * t)$$

$$a = 13 \frac{1}{4} \quad b = 7 \frac{1}{4} \quad B2 = 1.788$$

$$w = 220 / 13.25 = 16.7$$

$$fb = (1.788 * 16.7 * 7.25) / (4 * 4) = 13.45$$

WELD CALCULATIONS

$$W = (V * A * y) / (n * l * 12)$$

SECTION A-ATOP

$$V = 178 \quad A = 14 * 1.5 = 21$$

$$y = 11.75 - 5.8 = 5.95$$

$$l = 1500$$

$$W = .62$$

BOTTOM

$$V = 178 \quad A = 14 * 2 = 28$$

$$y = 5.8 - 1 = 4.8$$

$$l = 1500$$

$$W = .66$$

SECTION B-BTOP

$$A = 14 * 1.5 = 21$$

$$y = 15 - 6.88 = 8.12$$

$$V = 220 \quad l = 2957$$

$$W = .53$$

BOTTOM

$$A = 14 * 2.5 = 35$$

$$y = 6.88 - 1 = 5.88$$

$$V = 220 \quad l = 2957$$

$$W = .61$$

SECTION B5-B5TOP

$$A = 14 * 2.66 = 37.24$$

$$y = 19.83 - 10.75 = 9.08$$

$$V = 220 \quad I = 6782$$

$$W = .46$$

BOTTOM

$$A = 14 * 2.5 = 35$$

$$y = 10.75 - 1.25 = 9.5$$

$$V = 220 \quad I = 6782$$

$$W = .45$$

SECTION C-CTOP

$$A = 18 * 2.6 = 46.8$$

$$y = 23.1 - 13.07 = 10.03$$

$$V = 110 \quad I = 11001$$

$$W = .196$$

BOTTOM

$$A = 18 * 2 = 36$$

$$y = 13.07 - 1 = 12.07$$

$$V = 110 \quad I = 11001$$

$$W = .18$$

SECTION D-D

$$A = 52 * 2.5 = 130$$

$$y = 18.94 - 11.1 = 7.84$$

$$V = 110 \quad I = 18843$$

$$W = .25$$

APPENDIX B

FINITE ELEMENT ANALYSIS

ANSYS 4.3A
AUG 9 1989
10 28 32
PLOT NO. 1
PREP7 ELEMENTS

XV =1
YV =1
ZV =1
DIST=91.709
YF =1.001
ZF =-30.063
PRECISE HIDDEN