Fermilab

D0 Engineering Note

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September 23, 1986

**Forces on the Middle EC Module Connections
Resulting From Assembly Sequence A**

Bob Wands

Introduction

The ANSYS superelement model representing the sequential assembly of the ec modules has been used to calculate the maximum forces experienced at any interface between middle modules during assembly. The assembly sequence used was devised by GTM and is referred to as Sequence A. (see attached sheet for explanation of sequence).

Fig. 1 shows the assembled model and support. One-half symmetry is assumed. The superelement model supported the OCH modules at $\theta=56.25$ in such a way that the support was allowed to translate freely in the horizontal direction, and rotate freely about the longitudinal (beam) axis. This produces "worst case" module connecting forces, and is justified given the importance of these connections. The middle modules were supported within the OCH arch only through $\theta=56.25$.

Each middle module interface contained six connection points in the finite element model through which the forces were transmitted between modules. (see Fig. 2). In presenting the results here, the forces at the three connection locations at the inner radius of each interface were summed, and the

largest value found. This was also done for the outer radius. In applying these results to the design of the actual connections, the forces presented here should be divided by the actual number of connection points used.

Results

The force normal to each interface (FN) and the force parallel to each interface (FS) as well as the resolved force on the inner and outer locations was calculated and is included here as Appendix A.

The resulting maximum connecting forces for the inner and outer radii are:

Inner Radius: The maximum force at the inner radius is 35000 lbs. and occurs at $\theta=33.75$ for Step 30 of Assembly Sequence A. (Step 30 is the fully assembled structure)

Outer Radius: The maximum force at the outer radius is 48000 lbx. and occurs at $\theta=33.75$ for Step 30 of Assembly Sequence A. (Step 30 is the fully assembled structure)

Conclusion

The maximum loads occur when the EC modules (including the IFH) are fully assembled. No larger loads occur during the assembly process. The numbers presented here can be applied to the actual connection design by remembering that they represent the total force at each radius, and must be divided by the number of actual connection locations used. For example, if two connections are used at the inner and outer radii (for a total of four locations) the maximum load for a single connection is $48000/2$ or 24000 lbs.

Fig1. Schematic of EC Superelement Model. (Shown fully assembled)

Fig 2. Location of the six connection points at a typical EC middle module interface

August 23, 1986
 Memo to: File, and below
 Re: EC Module
 Assembly Sequence
 From: G.T. Mulholland

It has long been recognized the assembly sequence of the EC modules into the cryostat may create larger inter-modular stresses or lateral reactions than the fully assembled calorimeter. Guided by those things we have learned, a sense of symmetry, and the seat of my pants I suggest we begin with the investigation and documentation of the analysis for the following assembly sequences;

	A	B	C
1.	03L	03L	03L
2.	03R	03R	03R
3.	02L,01L,01R,02R	02L,01L,01R,02R	02L,01L,01R,02R
4.	04L	M0	M0
5.	04R	M1L	M1L
6.	05L	M1R	M1R
7.	05R	M2L	M2L
8.	06L	M2R	M2R
9.	06R	M3L	M3L
10.	07L	M3R	M3R
11.	07R	M4L	IH
12.	08L	M4R	M4L
13.	08R	M5L	M4R
14.	M0	M5R	M5R
15.	M1L	M6L	M5L
16.	M1R	M6R	M6R
17.	M2L	M7L	M6L
18.	M2R	M7R	M7R
19.	M3L	M8	M7L
20.	M3R	IH	M8
21.	M4L	04L	04L
22.	M4R	04R	04R
23.	M5L	05L	05R
24.	M5R	05R	05L
25.	M6L	06L	06L
26.	M6R	06R	06L
27.	M7L	07L	07L
28.	M7R	07R	07R
29.	M8	08L	07L
30.	IH	08R	08R

The modules are identified O for (outer numbered 1-8 beginning at the bottom), M for middle (numbered 0-8 beginning at the bottom), I for inner, and R for right and L for left of center as looking toward the detector center.

XC,EF,KK,PK,RL,DM,DO,SR,KW,RW.

Appendix A

***** STEP 14 ASSEMBLY SEQUENCE A *****
 ***** MIDDLE MODULES *****
 ***** 9/23/86 *****
 ***** THETA= 0.000 *****

FN AT INNER RADIUS= 0.000 FS AT INNER RADIUS= -0.000
 FN AT OUTER RADIUS= 0.000 FS AT OUTER RADIUS= -0.000
 FRI= .000 FRO= .000

NORMAL FORCE= 0.000 SHEAR= -0.000 MOMENT= 0.000

***** THETA= 11.250 *****
 FN AT INNER RADIUS= -0.000 FS AT INNER RADIUS= .000
 FN AT OUTER RADIUS= .000 FS AT OUTER RADIUS= 4474.986
 FRI= .000 FRO= 4474.986

NORMAL FORCE= .000 SHEAR= 4474.986 MOMENT= -0.000

***** STEPS 15-16 ASSEMBLY SEQUENCE A *****
***** MIDDLE MODULES *****
***** 9/23/60 *****
***** THETA= 0.000 *****
FN AT INNER RADIUS= 0.000 FS AT INNER RADIUS= .000
FN AT OUTER RADIUS= 0.000 FS AT OUTER RADIUS= .000
FRI= .000 FRO= .000

NORMAL FORCE= 0.000 SHEAR= .000 MOMENT= 0.000

***** THETA= 11.250 *****
FN AT INNER RADIUS= -6059.898 FS AT INNER RADIUS= -1572.848
FN AT OUTER RADIUS= 630.445 FS AT OUTER RADIUS= 1221.448
FRI= 6260.688 FRO= 1374.554

NORMAL FORCE= -5429.453 SHEAR= -351.400 MOMENT= -85636.391

***** THETA= 33.750 *****
FN AT INNER RADIUS= -.000 FS AT INNER RADIUS= .000
FN AT OUTER RADIUS= .001 FS AT OUTER RADIUS= 9708.374
FRI= .000 FRO= 9708.374

NORMAL FORCE= .001 SHEAR= 9708.374 MOMENT= -.000

***** STEPS 17-18 ASSEMBLY SEQUENCE A *****
***** MIDDLE MODULES *****
***** 9/23/86 *****
***** THETA= 0.000 *****
FN AT INNER RADIUS= 0.000 FS AT INNER RADIUS= .000
FN AT OUTER RADIUS= 0.000 FS AT OUTER RADIUS= .000
FRI= .000 FRO= .000

NORMAL FORCE= 0.000 SHEAR= .000 MOMENT= 0.000

***** THETA= 11.250 *****
FN AT INNER RADIUS= -15521.206 FS AT INNER RADIUS= -1741.997
FN AT OUTER RADIUS= 1168.697 FS AT OUTER RADIUS= 2947.751
FRI= 15616.655 FRO= 2622.527

NORMAL FORCE= -14352.569 SHEAR= 605.753 MOMENT= -213629.984

***** THETA= 33.750 *****
FN AT INNER RADIUS= -8720.096 FS AT INNER RADIUS= -3471.988
FN AT OUTER RADIUS= 109.919 FS AT OUTER RADIUS= 1757.458
FRI= 9385.882 FRO= 1760.893

NORMAL FORCE= -8610.177 SHEAR= -1714.529 MOMENT= -113024.197

***** THETA= 56.250 *****
FN AT INNER RADIUS= -.000 FS AT INNER RADIUS= .000
FN AT OUTER RADIUS= .004 FS AT OUTER RADIUS= 9755.789
FRI= .000 FRO= 9755.789

NORMAL FORCE= .004 SHEAR= 9755.789 MOMENT= -.046

 STEPS19-20 ASSEMBLY SEQUENCE A *****
 ***** MIDDLE MODULES *****
 ***** 9/23/86 *****

***** THETA= 0.000 *****

FN AT INNER RADIUS= 0.000 FS AT INNER RADIUS= .000
 FN AT OUTER RADIUS= 0.000 FS AT OUTER RADIUS= .000
 FRI= .000 FRO= .000

NORMAL FORCE= 0.000 SHEAR= .000 MOMENT= 0.000

***** THETA= 11.250 *****

FN AT INNER RADIUS= -15656.846 FS AT INNER RADIUS= -1484.252
 FN AT OUTER RADIUS= -5073.524 FS AT OUTER RADIUS= 4021.056
 FRI= 15727.042 FRO= 6473.757

NORMAL FORCE= -20730.370 SHEAR= 2536.804 MOMENT= -135466.532

***** THETA= 33.750 *****

FN AT INNER RADIUS= -9456.140 FS AT INNER RADIUS= -2729.079
 FN AT OUTER RADIUS= -5785.323 FS AT OUTER RADIUS= 4130.823
 FRI= 9840.967 FRO= 7108.703

NORMAL FORCE= -15241.462 SHEAR= 1405.744 MOMENT= -46986.460

***** THETA= 56.250 *****

FN AT INNER RADIUS= -2368.669 FS AT INNER RADIUS= -383.366
 FN AT OUTER RADIUS= -4951.917 FS AT OUTER RADIUS= 5274.833
 FRI= 2399.492 FRO= 7235.009

NORMAL FORCE= -7320.586 SHEAR= 4891.467 MOMENT= 33065.573

***** THETA= 78.750 *****

FN AT INNER RADIUS= -.000 FS AT INNER RADIUS= .000
 FN AT OUTER RADIUS= -.000 FS AT OUTER RADIUS= .000
 FRI= .000 FRO= .000

NORMAL FORCE= -.000 SHEAR= .000 MOMENT= -.000

 ***** STEPS 21-22 ASSEMBLY SEQUENCE A *****
 ***** MIDDLE MODULES *****
 ***** 9/23/66 *****

***** THETA= 0.000 *****

FN AT INNER RADIUS= 0.000 FS AT INNER RADIUS= .000
 FN AT OUTER RADIUS= 0.000 FS AT OUTER RADIUS= .000
 FRI= .000 FRO= .000

NORMAL FORCE= 0.000 SHEAR= .000 MOMENT= 0.000

***** THETA= 11.250 *****

FN AT INNER RADIUS= -14424.185 FS AT INNER RADIUS= -1241.437
 FN AT OUTER RADIUS= -12868.244 FS AT OUTER RADIUS= 5498.673
 FRI= 14477.509 FRO= 13993.038

NORMAL FORCE= -27292.429 SHEAR= 4255.236 MOMENT= -19916.043

***** THETA= 33.750 *****

FN AT INNER RADIUS= -8597.980 FS AT INNER RADIUS= -2230.003
 FN AT OUTER RADIUS= -13363.666 FS AT OUTER RADIUS= 6484.092
 FRI= 8882.465 FRO= 14853.654

NORMAL FORCE= -21961.646 SHEAR= 4254.089 MOMENT= 61000.779

***** THETA= 56.250 *****

FN AT INNER RADIUS= -2880.816 FS AT INNER RADIUS= 972.770
 FN AT OUTER RADIUS= -11738.609 FS AT OUTER RADIUS= 8795.502
 FRI= 3040.432 FRO= 14668.190

NORMAL FORCE= -14619.224 SHEAR= 9768.272 MOMENT= 113382.307

***** THETA= 78.750 *****

FN AT INNER RADIUS= -3616.358 FS AT INNER RADIUS= 1910.274
 FN AT OUTER RADIUS= -4992.977 FS AT OUTER RADIUS= -197.761
 FRI= 4089.887 FRO= 4996.892

NORMAL FORCE= -8609.333 SHEAR= 1712.513 MOMENT= 17620.792

***** THETA= 101.250 *****

FN AT INNER RADIUS= -.000 FS AT INNER RADIUS= .000
 FN AT OUTER RADIUS= .000 FS AT OUTER RADIUS= .000
 FRI= .000 FRO= .000

NORMAL FORCE= -.000 SHEAR= .000 MOMENT= -.000

 ***** STEPS 23-24 ASSEMBLY SEQUENCE A *****
 ***** MIDDLE MODULES *****
 ***** 9/23/86 *****

***** THETA= 0.000 *****
 FN AT INNER RADIUS= 0.000 FS AT INNER RADIUS= .000
 FN AT OUTER RADIUS= 0.000 FS AT OUTER RADIUS= .000
 FRI= .000 FRO= .000
 NORMAL FORCE= 0.000 SHEAR= .000 MOMENT= 0.000

***** THETA= 11.250 *****
 FN AT INNER RADIUS= -14245.036 FS AT INNER RADIUS= -951.941
 FN AT OUTER RADIUS= -19827.505 FS AT OUTER RADIUS= 7262.671
 FRI= 14276.807 FRO= 21115.784
 NORMAL FORCE= -34072.541 SHEAR= 6310.730 MOMENT= 71455.807

***** THETA= 33.750 *****
 FN AT INNER RADIUS= -9059.509 FS AT INNER RADIUS= -1516.256
 FN AT OUTER RADIUS= -19952.739 FS AT OUTER RADIUS= 9154.564
 FRI= 9185.518 FRO= 21952.627
 NORMAL FORCE= -29012.248 SHEAR= 7638.309 MOMENT= 139433.339

***** THETA= 56.250 *****
 FN AT INNER RADIUS= -5136.418 FS AT INNER RADIUS= 2615.704
 FN AT OUTER RADIUS= -17289.788 FS AT OUTER RADIUS= 12370.370
 FRI= 5765.869 FRO= 21259.417
 NORMAL FORCE= -22428.205 SHEAR= 14986.075 MOMENT= 135537.559

***** THETA= 78.750 *****
 FN AT INNER RADIUS= -9195.635 FS AT INNER RADIUS= 2958.674
 FN AT OUTER RADIUS= -8625.030 FS AT OUTER RADIUS= 594.098
 FRI= 9657.442 FRO= 8645.467
 NORMAL FORCE= -17820.665 SHEAR= 3544.772 MOMENT= -7309.749

***** THETA= 101.250 *****
 FN AT INNER RADIUS= -5579.281 FS AT INNER RADIUS= -402.448
 FN AT OUTER RADIUS= -3632.057 FS AT OUTER RADIUS= -1429.785
 FRI= 5593.778 FRO= 3903.348
 NORMAL FORCE= -9211.338 SHEAR= -1832.234 MOMENT= -24924.477

***** THETA= 123.750 *****
 FN AT INNER RADIUS= .000 FS AT INNER RADIUS= .000
 FN AT OUTER RADIUS= .000 FS AT OUTER RADIUS= .000
 FRI= .000 FRO= .000
 NORMAL FORCE= .000 SHEAR= .000 MOMENT= -.000

***** STEPS 25-26 ASSEMBLY SEQUENCE A *****
***** MIDDLE MODULES *****
***** 9/23/86 *****

***** THETA= 0.000 *****
FN AT INNER RADIUS= 0.000 FS AT INNER RADIUS= .000
FM AT OUTER RADIUS= 0.000 FS AT OUTER RADIUS= .000
PRI= .000 FRO= .000

NORMAL FORCE= 0.000 SHEAR= .000 MOMENT= 0.000

***** THETA= 11.250 *****
FN AT INNER RADIUS= -16664.778 FS AT INNER RADIUS= -614.668
FM AT OUTER RADIUS= -23203.113 FS AT OUTER RADIUS= 9338.821
PRI= 16676.110 FRO= 25011.957

NORMAL FORCE= -39867.890 SHEAR= 8724.153 MOMENT= 83690.684

***** THETA= 33.750 *****
FN AT INNER RADIUS= -12621.887 FS AT INNER RADIUS= -428.403
FM AT OUTER RADIUS= -22668.144 FS AT OUTER RADIUS= 11983.045
PRI= 12629.155 FRO= 25640.556

NORMAL FORCE= -35290.031 SHEAR= 11554.642 MOMENT= 128592.091

***** THETA= 56.250 *****
FN AT INNER RADIUS= -11118.691 FS AT INNER RADIUS= 4374.851
FM AT OUTER RADIUS= -18608.124 FS AT OUTER RADIUS= 15488.014
PRI= 11948.415 FRO= 24210.346

NORMAL FORCE= -29726.815 SHEAR= 19862.865 MOMENT= 98864.735

***** THETA= 78.750 *****
FN AT INNER RADIUS= -18280.315 FS AT INNER RADIUS= 3064.591
FM AT OUTER RADIUS= -8149.684 FS AT OUTER RADIUS= 1292.695
PRI= 18705.291 FRO= 8251.570

NORMAL FORCE= -26429.999 SHEAR= 5257.286 MOMENT= -129672.083

***** THETA= 101.250 *****
FN AT INNER RADIUS= -14663.983 FS AT INNER RADIUS= -1426.001
FM AT OUTER RADIUS= -3156.704 FS AT OUTER RADIUS= -2118.726
PRI= 14733.156 FRO= 3801.813

NORMAL FORCE= -17820.688 SHEAR= -3544.727 MOMENT= -147293.166

***** THETA= 123.750 *****
FN AT INNER RADIUS= -5980.280 FS AT INNER RADIUS= -2015.064
FM AT OUTER RADIUS= -1318.364 FS AT OUTER RADIUS= -2861.714
PRI= 6310.645 FRO= 3150.792

NORMAL FORCE= -7298.645 SHEAR= -4876.778 MOMENT= -59672.521

***** THETA= 146.250 *****
FN AT INNER RADIUS= -.000 FS AT INNER RADIUS= -.000
FM AT OUTER RADIUS= .000 FS AT OUTER RADIUS= .000
PRI= .000 FRO= .000

 ***** STEPS 27-28 ASSEMBLY SEQUENCE A *****
 ***** MIDDLE MODULES *****
 ***** 9/23/86 *****

***** THETA= 0.000 *****

FN AT INNER RADIUS= 0.000 FS AT INNER RADIUS= .000
 FN AT OUTER RADIUS= 0.000 FS AT OUTER RADIUS= .000
 FRI= .000 FRO= .000

NORMAL FORCE= 0.000 SHEAR= .000 MOMENT= 0.000

***** THETA= 11.250 *****

FN AT INNER RADIUS= -22752.286 FS AT INNER RADIUS= -183.111
 FN AT OUTER RADIUS= -22151.599 FS AT OUTER RADIUS= 12012.032
 FRI= 22753.039 FRO= 25198.664

NORMAL FORCE= -44903.885 SHEAR= 11826.941 MOMENT= -7688.788

***** THETA= 33.750 *****

FN AT INNER RADIUS= -20613.826 FS AT INNER RADIUS= 1220.129
 FN AT OUTER RADIUS= -20516.268 FS AT OUTER RADIUS= 15277.556
 FRI= 20651.700 FRO= 25579.698

NORMAL FORCE= -41130.094 SHEAR= 16527.715 MOMENT= -1248.742

***** THETA= 56.250 *****

FN AT INNER RADIUS= -22565.345 FS AT INNER RADIUS= 6454.089
 FN AT OUTER RADIUS= -14460.154 FS AT OUTER RADIUS= 18285.608
 FRI= 23470.194 FRO= 23312.218

NORMAL FORCE= -37025.499 SHEAR= 24739.693 MOMENT= -103746.445

***** THETA= 78.750 *****

FN AT INNER RADIUS= -32831.335 FS AT INNER RADIUS= 6956.171
 FN AT OUTER RADIUS= -2208.017 FS AT OUTER RADIUS= 2013.631
 FRI= 33203.317 FRO= 2988.319

NORMAL FORCE= -35039.352 SHEAR= 6969.802 MOMENT= -391978.484

***** THETA= 101.250 *****

FN AT INNER RADIUS= -29214.949 FS AT INNER RADIUS= -2382.708
 FN AT OUTER RADIUS= 2784.962 FS AT OUTER RADIUS= -2874.509
 FRI= 29311.952 FRO= 4002.351

NORMAL FORCE= -26429.987 SHEAR= -5257.217 MOMENT= -409598.853

***** THETA= 123.750 *****

FN AT INNER RADIUS= -17426.882 FS AT INNER RADIUS= -4780.838
 FN AT OUTER RADIUS= 2829.583 FS AT OUTER RADIUS= -4972.724
 FRI= 18070.768 FRO= 5721.410

NORMAL FORCE= -14597.299 SHEAR= -9753.563 MOMENT= -259282.756

***** THETA= 146.250 *****

FN AT INNER RADIUS= -5710.396 FS AT INNER RADIUS= -3495.686
 FN AT OUTER RADIUS= 633.594 FS AT OUTER RADIUS= -3802.939
 FRI= 6645.405 FRO= 3893.227

NORMAL FORCE= -4876.803 SHEAR= -7298.624 MOMENT= -83763.073

***** THETA= 166.750 *****
FN AT INNER RADIUS= .000 FS AT INNER RADIUS= -.000
FN AT OUTER RADIUS= .000 FS AT OUTER RADIUS= .000

FR1= .000 FR2= .000

NORMAL FORCE= .000 SHEAR= .000 MOMENT= -.000

 ***** STEP 26 ASSEMBLY SEQUENCE A *****
 ***** MIDDLE MODULES *****
 ***** 9/23/86 *****

***** THETA = 0.000 *****

FN AT INNER RADIUS = 0.000 FS AT INNER RADIUS = .000
 FN AT OUTER RADIUS = 0.000 FS AT OUTER RADIUS = .000
 FRI = .000 FRO = .000

NORMAL FORCE = 0.000 SHEAR = .000 MOMENT = 0.000

***** THETA = 11.250 *****

FN AT INNER RADIUS = -21334.879 FS AT INNER RADIUS = -58.424
 FN AT OUTER RADIUS = -26757.577 FS AT OUTER RADIUS = 12662.550
 FRI = 21334.959 FRO = 29602.502

NORMAL FORCE = -48092.457 SHEAR = 12604.126 MOMENT = 69410.537

***** THETA = 33.750 *****

FN AT INNER RADIUS = -19325.952 FS AT INNER RADIUS = 1461.481
 FN AT OUTER RADIUS = -25047.321 FS AT OUTER RADIUS = 16430.763
 FRI = 19381.134 FRO = 29955.605

NORMAL FORCE = -44373.273 SHEAR = 17692.243 MOMENT = 73233.514

***** THETA = 56.250 *****

FN AT INNER RADIUS = -21929.460 FS AT INNER RADIUS = 7224.029
 FN AT OUTER RADIUS = -18614.513 FS AT OUTER RADIUS = 20149.875
 FRI = 23068.694 FRO = 27432.053

NORMAL FORCE = -40543.973 SHEAR = 27373.904 MOMENT = -42431.319

***** THETA = 78.750 *****

FN AT INNER RADIUS = -33948.753 FS AT INNER RADIUS = 5604.810
 FN AT OUTER RADIUS = -5349.267 FS AT OUTER RADIUS = 2452.219
 FRI = 34408.309 FRO = 5884.559

NORMAL FORCE = -39298.020 SHEAR = 8057.028 MOMENT = -366073.420

***** THETA = 101.250 *****

FN AT INNER RADIUS = -30550.087 FS AT INNER RADIUS = -2734.323
 FN AT OUTER RADIUS = -230.534 FS AT OUTER RADIUS = -3148.159
 FRI = 30672.207 FRO = 3156.588

NORMAL FORCE = -30780.620 SHEAR = -5082.481 MOMENT = -368090.274

***** THETA = 123.750 *****

FN AT INNER RADIUS = -17410.873 FS AT INNER RADIUS = -6030.990
 FN AT OUTER RADIUS = -966.590 FS AT OUTER RADIUS = -5965.137
 FRI = 18425.834 FRO = 6042.943

NORMAL FORCE = -18377.463 SHEAR = -11996.128 MOMENT = -210486.818

***** THETA = 146.250 *****

FN AT INNER RADIUS = -2980.194 FS AT INNER RADIUS = -5450.619
 FN AT OUTER RADIUS = -4530.838 FS AT OUTER RADIUS = -5366.486
 FRI = 6212.156 FRO = 7023.365

NORMAL FORCE= -7511.032 SHEAR= -10817.105 MOMENT= 19848.236

***** THETA= 166.750 *****
FN AT INNER RADIUS= 6394.273 FS AT INNER RADIUS= -2558.934
FN AT OUTER RADIUS= -7481.508 FS AT OUTER RADIUS= -1699.787
FRI= 6887.297 FRO= 7672.173

NORMAL FORCE= -1067.235 SHEAR= -4258.721 MOMENT= 177609.992

***** THETA= 180.000 *****
FN AT INNER RADIUS= -.000 FS AT INNER RADIUS= -.000
FN AT OUTER RADIUS= .000 FS AT OUTER RADIUS= .000
FRI= .000 FRO= .000

NORMAL FORCE= -.000 SHEAR= -.000 MOMENT= -.000