MFH Top-Half Ring Connectors

D-Zero Engineering Note #3740.225-EN-195

Rob Nachtrieb
10-24-88

Approved by Keith Primdahl

Keith Primdahl

The purpose of the test was to experimentally verify that the connector scheme designed for the top half of the MH ring (end calorimeter) was adequate for the expected structural loads. The test proved that the design was acceptable.

Background

In the end calorimeter of the D-zero experiment, uranium and stainless steel plates are assembled into modules which are to be installed into the cryostat as individual units. A single inner module will be surrounded by 16 middle modules, which are surrounded by 16 outer modules. The 16 modules which comprise the middle ring are to be connected at the outer radius by a link, which is pinned to each front plate. The expected forces at each of the 16 connections vary from 1400 lb to 69,000 lb (Appendix 1). At the inner radius, the forces are known to be compressive; hence, the edges of the front plates will be allowed to bear directly upon one another.

Since it is desirable to minimize the volume of material used, an Inconnel connector plate and pins were chosen. Furthermore, it was observed that the forces between the 9 modules of the top half of the ring are all less than 7,700 lb. Accordingly, a connector was designed for the top half of the ring, with the intention that a separate design be performed for the bottom connections.

Test Setup

We tested an Inconnel 3" x 8" x .25" connector plate, a stainless steel cover plate, and a portion of a stainless steel front plate, using two Enerpac model RC-251 hydraulic cylinders. The cylinders were powered by the same pump, with an effective total area of 10.30 in^2. The Inconnel plate and pins had been solution annealed, then age-hardened (a heat-treatment) to realize the full capability of Inconnel. This process will be described in more detail in a separate report. Dimensions were carefully measured before assembly.

The Inconnel connector plate was assembled between the front plate and the stainless steel cover plate, and secured with a 0.75" Inconnel pin. The cover plate was attached with two 0.625" Inconnel pins and a single 0.5" stainless steel bolt (figure 1). To measure strain of the Inconnel connector plate, four $0\text{-}60^0\text{-}120^0$ rosette strain-gages were employed. The movement of the pin end center points was measured with four separate surveyor's sighting

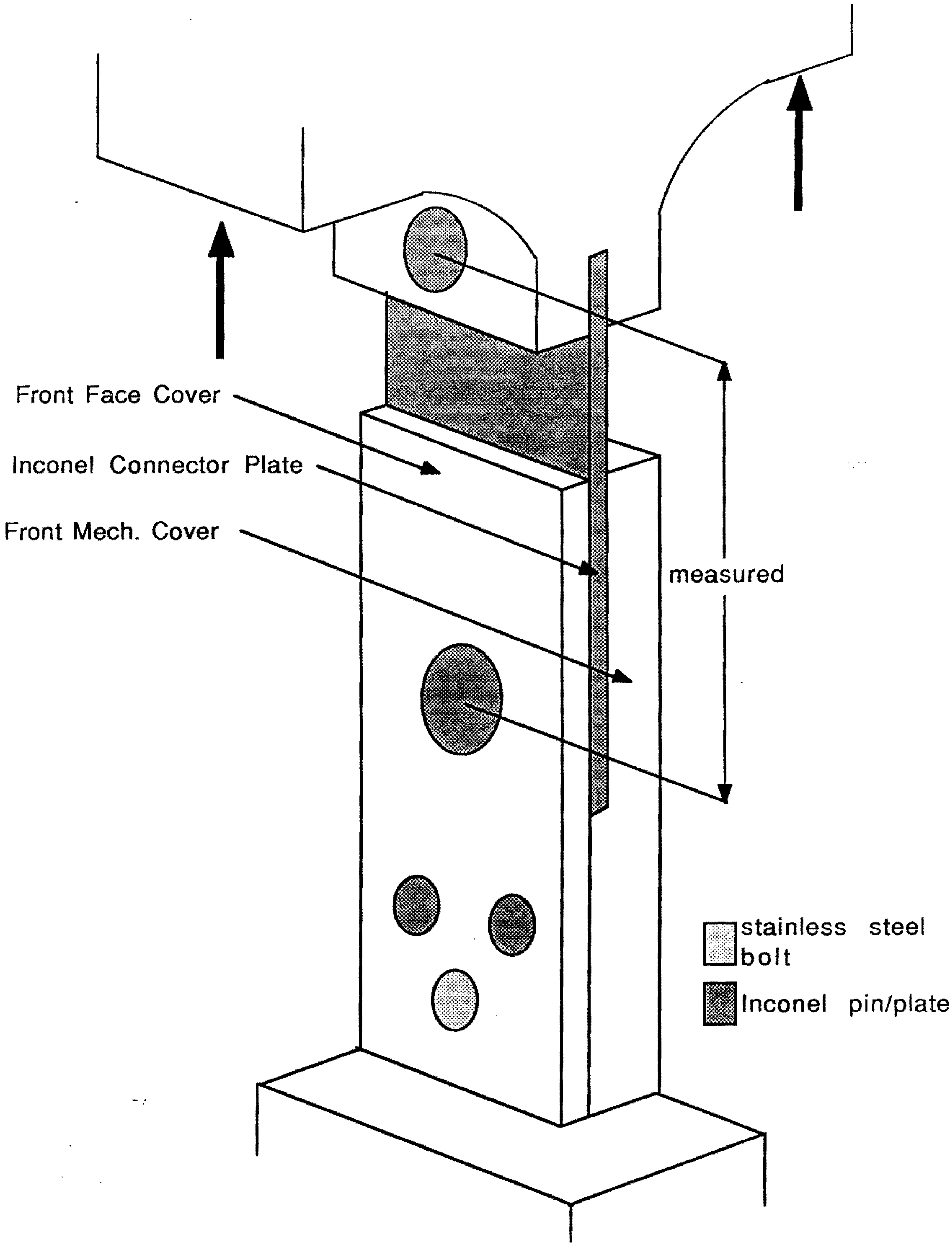


Figure 1: Test Set up

instruments, all calibrated to the same reference point. The difference between the pin heights was used to determine the elongation between the pins.

Procedure

Starting at 400 psi, the load was increased by increments of 200 psi, recording the strain gage readings and elongation at each interval. The combined surface area of the hydraulic jacks was 10.30 in^2; accordingly, each successive 200 psi increase generated an additional 2060 lb. Pressure was decreased in similar increments back down to 400 psi. At each increment, we measured the clearance between the bottom of the cover and front plates by using a feeler gage. Two cycles to 10,300 lb resulted in consistent data.

The load was then increased, in 200 psi increments, until permanent deformation was evident Finally, the connector was disassembled and dimensions compared to those from before testing.

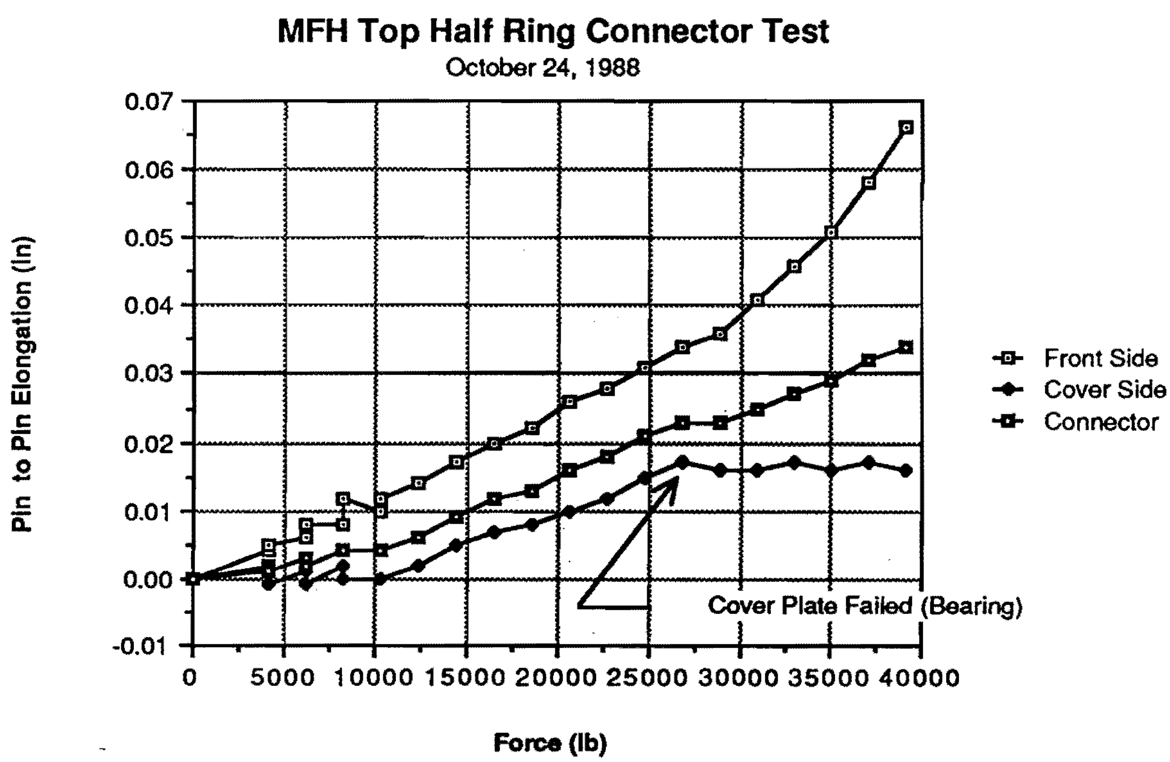


Figure 2: Pin to Pin Elongation

Results

When tested to 1.25 times the design load, the connector deformed elasticity, with nearly duplicate results on the second cycle. The cover plate moved a couple of mills with respect to the front plate, but did not completely return when unloaded. The cover plate slipped until the 0.625" pins came into full bearing, after which the deflection was elastic.

Failure occurred near 27,000 lb. In Figure 2, pin to pin elongation is plotted as a function of load. At the point of failure, the 0.75" pin began to deflect unevenly. The data for the cover plate side indicates that beyond 27,000 lb there is no further pin to pin elongation; in fact, the 0.75" pin was tearing its way through the cover plate. The front plate side's elongation subsequently appears to increase in slope; however, this was merely a result of the changing pitch of the pin.

The strain gages verified the the loading via the hydraulic cylinders was accurately measured. The Inconnel performed elasticity as can be seen in figure 3. The permanent deformation of

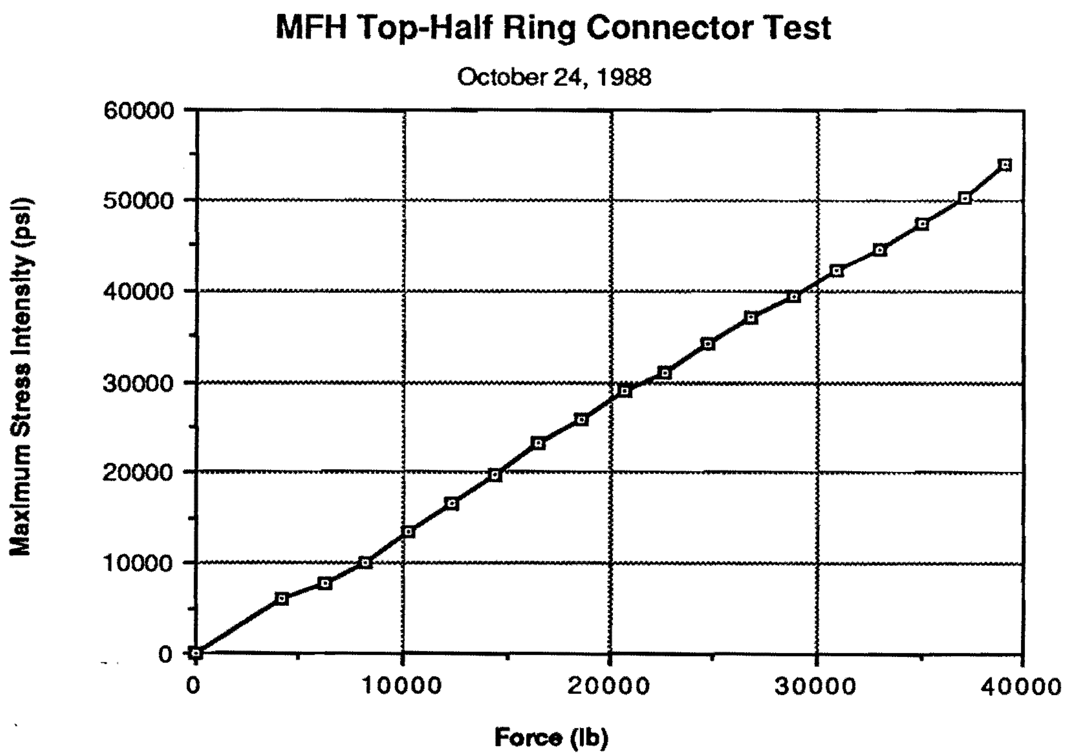


Figure 3: Inconnel Link Stress Intensity

the parts (figure 4) shows that the greatest deformation occurred in the stainless steel cover plate about the 0.75" pin. A small local deformation occurred in the Inconnel plate due to the twisting effect of the 0.075" pin.

Conclusion

The connector design is acceptable for the loads expected between modules of the top half of the MH ring.

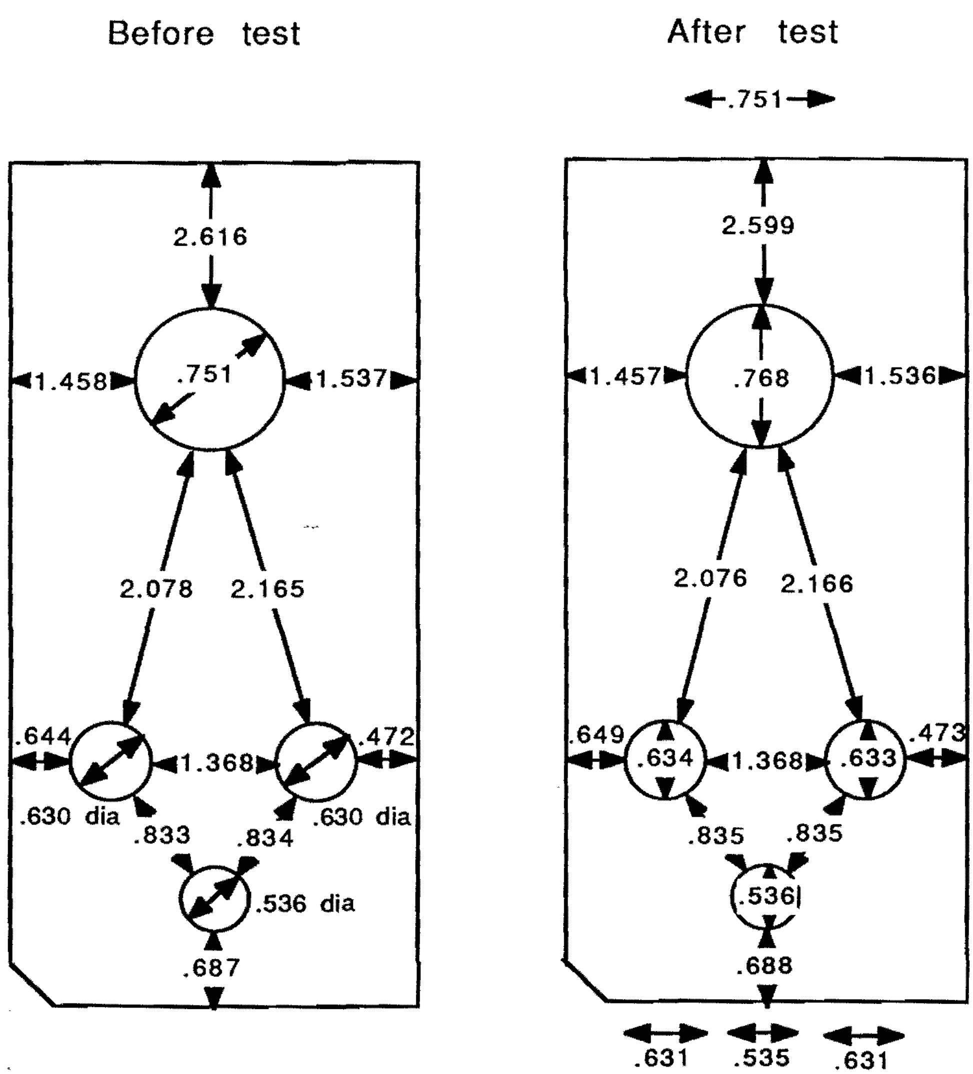
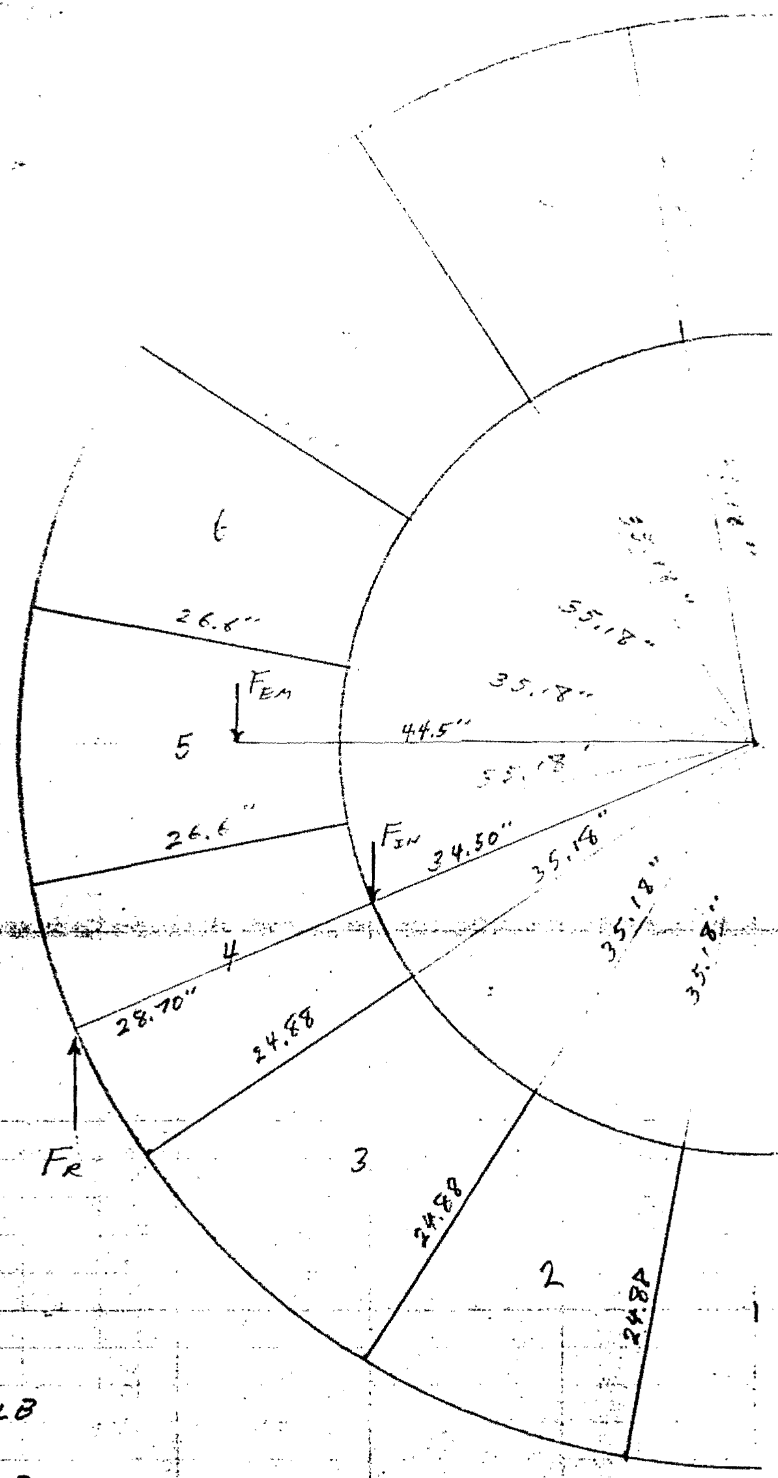


Figure 4: Cover Plate Dimensions

Appendix 1

Connector Force Calculations

[illegible]	[illegible]	F_{en} [illegible]	F_{sn} [illegible]	F_s [illegible]
[illegible]	[illegible]	$68.2 + 19.1\mu$	-68.2	2.6
2-[illegible]	[illegible]	$68.1 +$ [illegible]	-65.1	[illegible]
[illegible]	[illegible]	$67.5 - 16.7\mu$	-58.4	5.9
[illegible]	[illegible]	[illegible]	-50.9	5.2
5-6	[illegible]	[illegible]	-28.6	4.2
6-7	123.75	6.8	-20.1	8.9
7-8	146.25	4.0	-10.0	8.9
8-9	168.75	1.4	-2.4	5.2



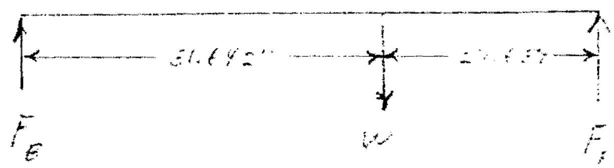
$F_{IN} = 18,000\ LB$

$F_{EM} = 4,000\ LB$

$F_R = 18,000\ LB + 4000\ LB + (8)(5340\ LB) = 64\ 720\ LB$

JH

MH



ASSUME $W \leq 10{,}000\,LB$

$$\sum M_E = -(31.642\,in)(10{,}000\,LB) - (59.28\,in)(F_F) = 0$$

$$F_F = 5340\,LB$$

CENTROID LOCATIONS:

	$\bar{X}$ (IN)	$\bar{Y}$ (IN)	W (LB)
1	-4.80	-49.33	2670
2	-18.97	-45.79	5340
3	-35.06	-35.06	5340
4	-45.79	-18.97	5340
5	-49.56	0	5340
6	-45.79	18.97	5340
7	-35.06	35.06	5340
8	-18.97	45.79	5340
9	0	49.56	5340

[illegible]

F_R = [illegible]

ΣM = [illegible]

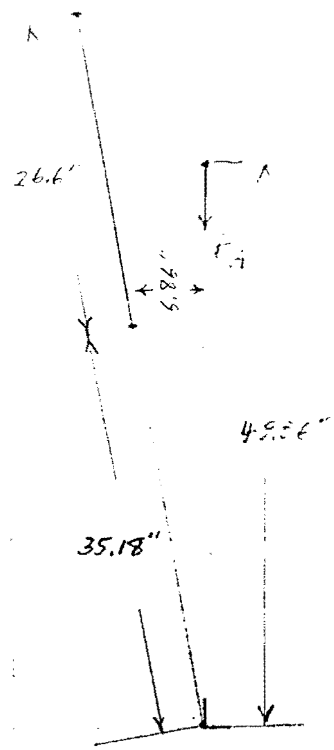
[illegible]

F_{CR} = 1377 LB (TENSION)

$F_{IR} = -(1377\ LB + (5340\ LB) \sin 11.25°)$

$F_{IR} = -2419\ LB$ (COMPRESSION)

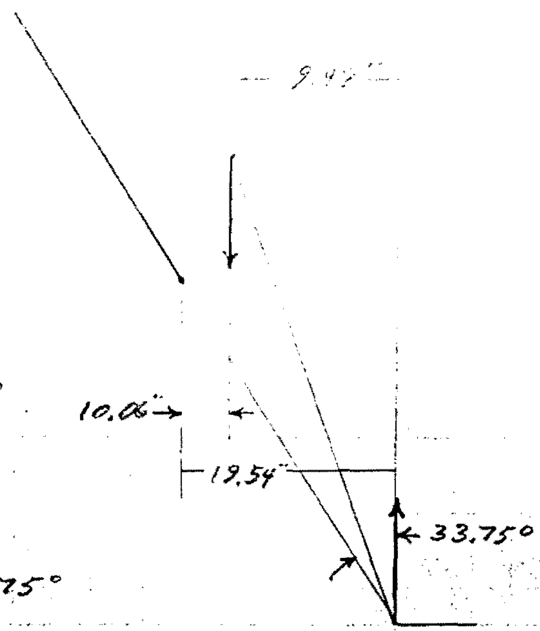
$F_S = (5340\ LB)(\cos 11.25°) = 5237\ LB$



[illegible]

$\bar{r} = [\ldots]$ [illegible]

$\bar{r} = [\ldots + \ldots]^{\frac{1}{2}} = 47.17$ in



$W = 10680$ LB

$\sum M_{IR} = -(10.06\,in)(10680\,LB) + (26.6\,in)(F_{OR}) = 0$

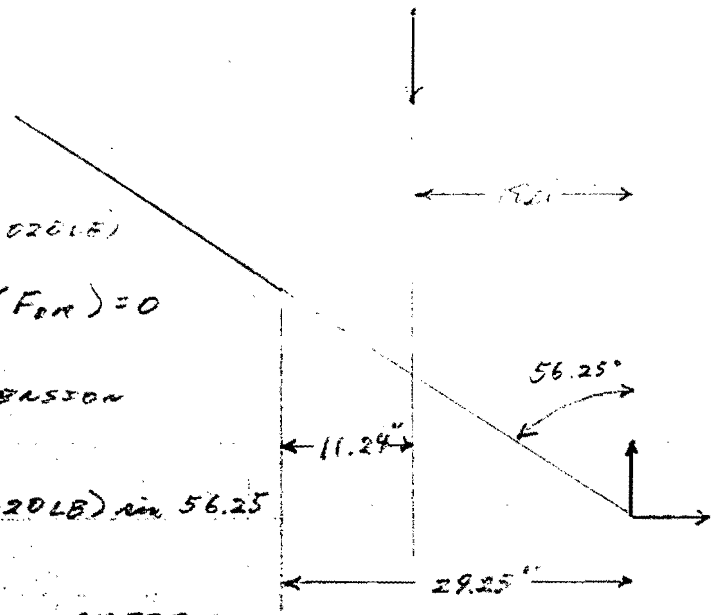
$F_{OR} = 4039$ LB TENSION

$F_{IR} = (-4039\,LB) - (10680\,LB)\sin 33.75°$

$F_{IR} = -9972$ LB COMPRESSION

$F_{[illegible]} = (10680\,LB)\cos 33.75 = 8880$ LB

16020 LB



$\Sigma M_{IR} = -(11.24")(16020\,LB) + (26.6")(F_{ER}) = 0$

$F_{ER} = 6769\,LB$ TENSION

$F_{IR} = -6769\,LB - (16020\,LB)\sin 56.25$

$F_{IR} = -20089\,LB$ COMPRESSION

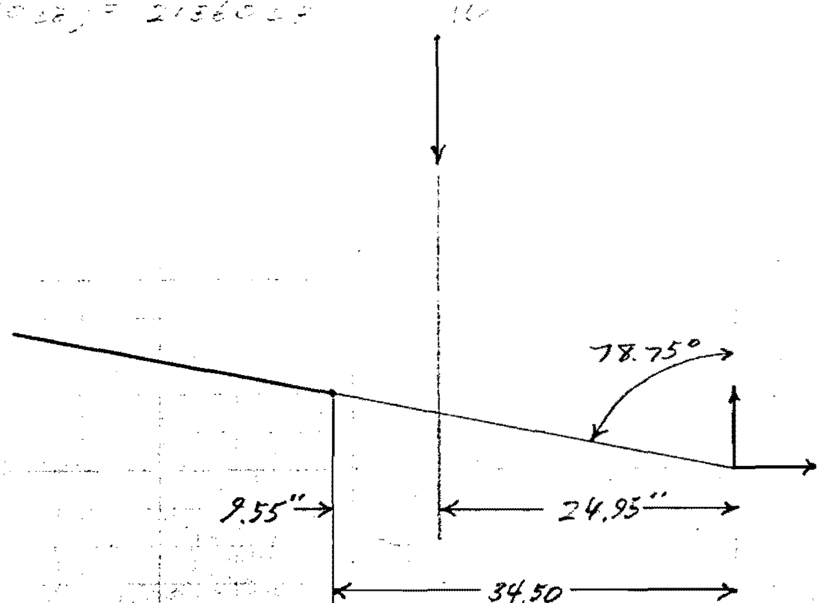
$F_S = (16020\,LB)\cos 56.25 = 8900\,LB$

[illegible]

[illegible]

[illegible]

W = (4)(5340 LB) = 21360 LB



$\Sigma M_{IR} = -(9.55\,in)(21360\,LB) + (26.6\,in)(F_{OR}) = 0$

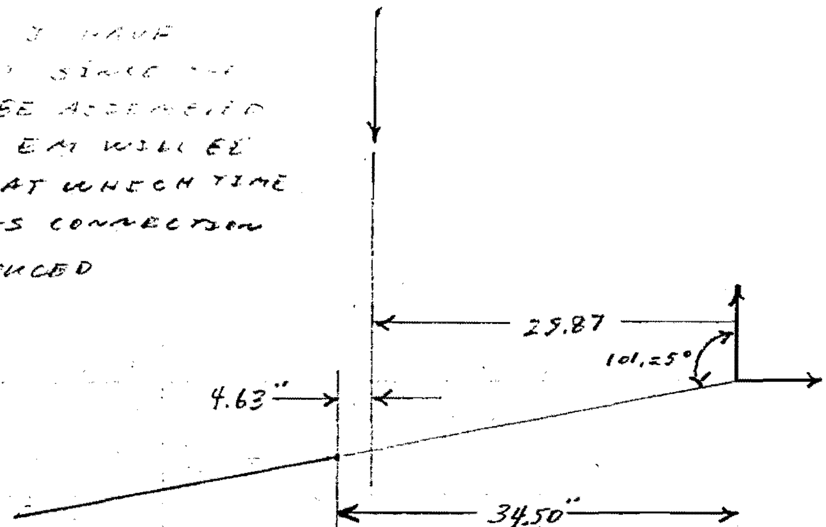
$F_{OR} = 7669\,LB$ TENSION

$F_{IR} = -7669\,LB - (21360\,LB)\sin(78.75°)$

$F_{IR} = -28619\,LB$ COMPRESSION

$F_S = (21360\,LB)\cos(78.75) = 4167\,LB$

NOTE: HERE I HAVE IGNORED EM SINCE THE RING WILL BE ASSEMBLED FIRST, THEN EM WILL BE INSTALLED, AT WHICH TIME F_{OR} FOR THIS CONNECTION WILL BE REDUCED



$$\Sigma M_{IR} = -(-4.63")(26700\,LB) + (26.6")(F_{OR}) = 0$$

$$F_{OR} = 4647\,LB$$

$$F_{IR} = -4647\,LB - (26700\,LB)\sin(101.25°) =$$

$$F_{IR} = -30834\,LB$$

$$F_S = (26700\,LB)\cos(101.25°) = 5209\,LB$$

WITH EM AND IH (IF ATTACHED TO S)

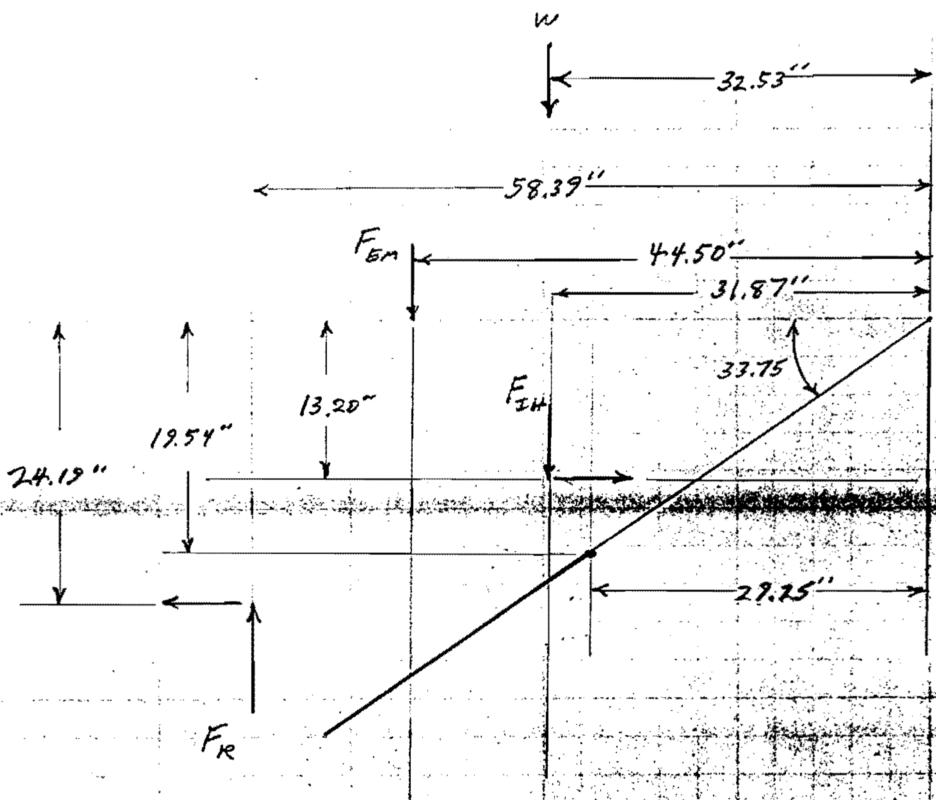
$$F_S = (26700\,LB + 4000\,LB + 18{,}000\,LB)\cos(101.25) = 9501\,LB$$

[illegible] SECTIONS 3 & 4

$\bar{X} = \left[-43.79 - [illegible] - 18.97 - 0\right]\frac{1}{6} = -32.53$ in

$\bar{Y} = \left[[illegible] + 49.56\right]\frac{1}{6} = 21.75$ in

W = (6 [illegible]) = 32040 LB



$$\Sigma M_{IR} = (3.28")(32040\,LB) + (15.25")(4000\,LB) - (24.88")(F_{OR})$$
$$+ (2.62")(18{,}000\,LB) - (29.14")(64{,}720\,LB) = 0$$

$F_{OR} = 67230\,LB$ TENSION

$F_{IR} = -67230\,LB - (32040\,LB + 4000\,LB + 18{,}000\,LB - 64720\,LB)\sin 123.75°$

$F_{IR} = -58350\,LB$ COMPRESSION

$F_S = (64720\,LB - 4000\,LB - 18{,}000\,LB - 32040\,LB)\cos 123.75°$

$F_S = 5933\,LB$

CONSIDER COOLDOWN

ASSUME $\mu_{SLIDING} = \frac{1}{2}\mu$

ASSUME IH CONNECTION IS SLIDING
OH CONNECTION IS STICKING

$$\Sigma M_{IR} = -(6.34")(18,000\,LB)(\tfrac{1}{2}\mu) - (4.65")(64720\,LB)(\mu) - (24.88")(F_{OR,f}) = 0$$

$$F_{OR,f} = (-14389\,LB)\,\mu$$

FRICTION DUE TO COOLDOWN "UNSTRESSES" THIS CONNECTOR, ASSUMING WARMUP MEANS ONLY A SIGN CHANGE:

$$F_{OR,f} = (67,500\,LB) + (4400\,LB)\,\mu$$

ALSO, SINCE FRICTION ON IH & OH BOTH RESULT IN A MOMENT OF THE SAME SIGN, A MORE CONSERVATIVE ASSUMPTION (FOR THIS CONNECTOR ONLY) WOULD BE THAT BOTH CONNECTIONS ARE STICKING:

$$\Sigma M_{IR} = -(6.34")(18,000\,LB)\,\mu + -(4.65")(64720\,LB)\,\mu + (24.88")(F_{OR,f}) = 0$$

$$F_{OR,f} = -16,683\,LB$$

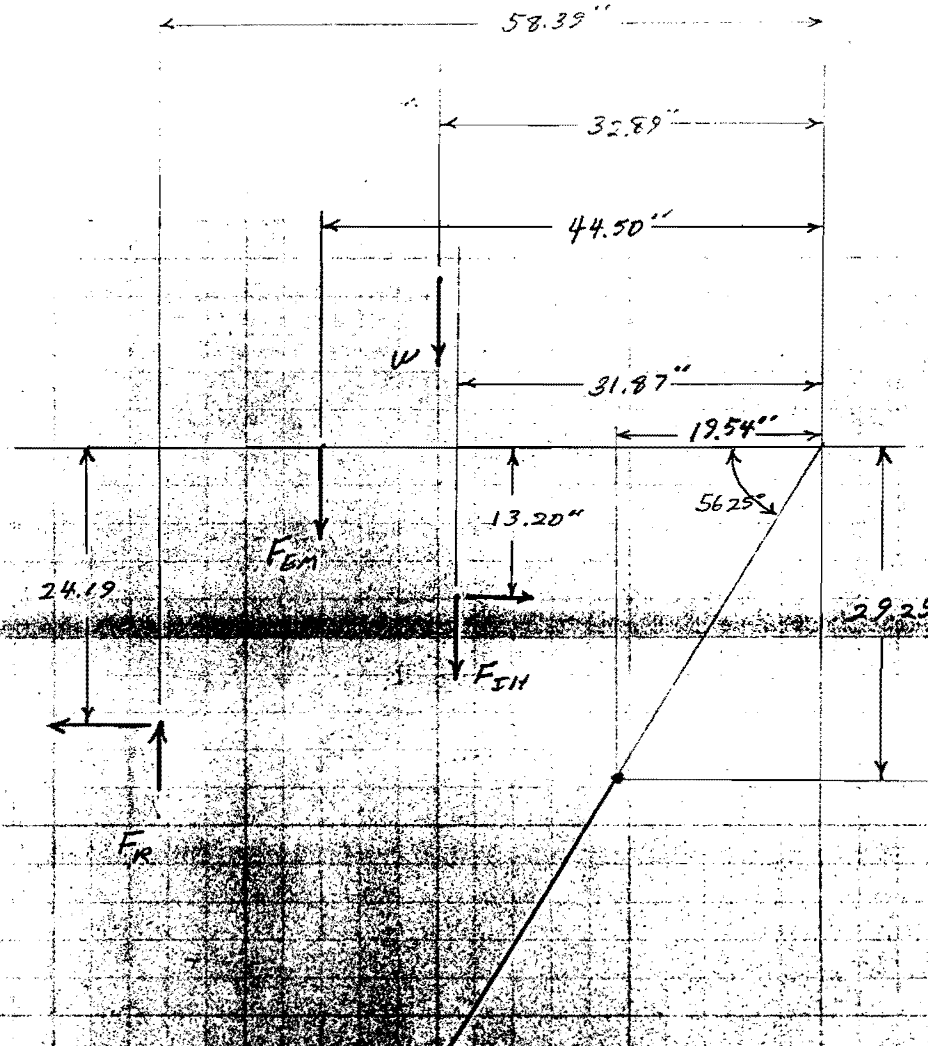
$$F_{OR} = (67,300\,LB) + (16,700\,LB)\,\mu$$

CONNECTION BETWEEN 2 & 3

$$\bar{x} = \left[-35.06 - 45.79 - 49.56 - 45.79 - 35.06 - 18.97 - 0\right]\frac{1}{7} = -32.89''$$

$$\bar{y} = \left[-35.06 - 18.97 - 0 + 18.97 + 35.06 + 45.79 + 49.56\right]\frac{1}{7} = 13.62''$$

$W = (7)(5340\,LB) = 37380\,LB$



$$\Sigma M_{IR} = (13.25'')(37380\,LB) + (24.76'')(4000\,LB) - (24.88'')(F_{OR})$$

$$\pm (12.33'')(18{,}000\,LB) - (33.85'')(64{,}720\,LB) = 0$$

$F_{OR} = 68{,}069\,LB$

$F_{IR} = (-68{,}069\,LB) - (37380\,LB + 4000\,LB + 18000\,LB - 64720\,LB)\sin 146.25°$

$F_{IR} = -65103\,LB$ COMPRESSION

$F_s = (64720\,LB - 4000\,LB$ [illegible]

[illegible]

CONSIDER FRICTION

ASSUME [illegible] $= \frac{1}{2}\mu$

ASSUME IR CONNECTION IS SLIDING
OR CONNECTION IS STICKING

$$\sum M_{IR} = (-16.05'')(18{,}000\,LB)(\tfrac{1}{2}\mu) + (5.06'')(64720\,LB) - (24.88'')(F_{OR,f}) = 0$$

$$F_{OR,f} = (7357\,LB)\mu$$

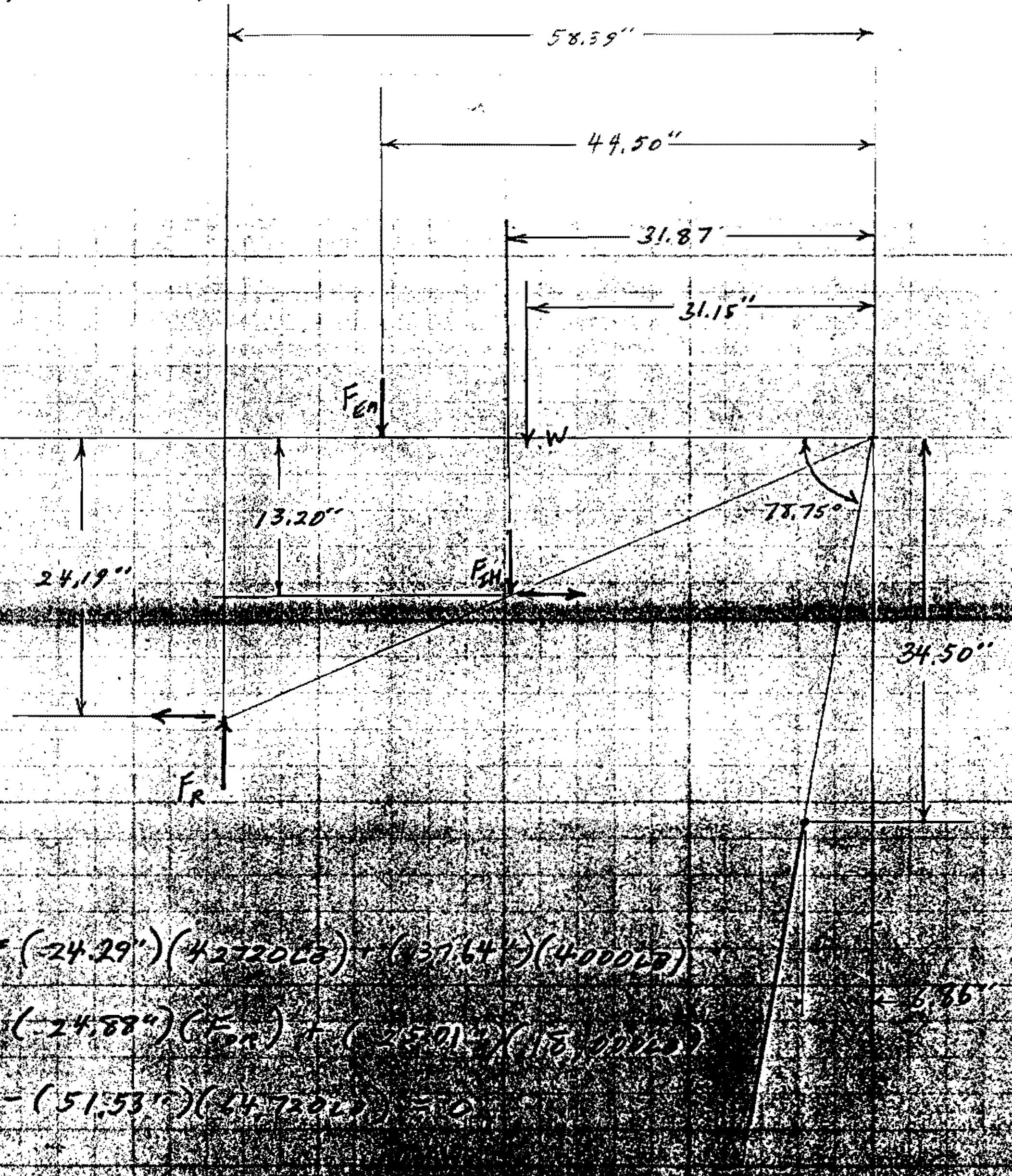
$$F_{OR,f} = (68{,}100\,LB) + (7{,}400\,LB)\mu$$

CONNECTION BETWEEN 1 & 2

$$\bar{X} = \left[-18.97 - 35.06 - 45.79 - 49.56 - 45.79 - 35.06 - 18.97 + 0\right]\frac{1}{8} = -31.15''$$

$$\bar{Y} = \left[-45.79 - 35.06 - 18.97 - 0 + 18.97 + 35.06 + 45.79 + 49.56\right]\frac{1}{8} = 6.19''$$

$$W = (8)(5340\,LB) = 42720\,LB$$



$$\Sigma M_{IR} = (-24.29'')(42720\,LB) + (37.64'')(4000\,LB)$$
$$-(-24.88'')(F_{OR}) + (-23.01'')(18{,}000\,LB)$$
$$-(51.53'')(24720\,LB) = 0$$

$$F_{OR} = 68{,}192\,LB$$

$$F_{IR} = (-68{,}192\,LB) - (42720\,LB + 4000\,LB + 18000\,LB - 64720\,LB)\sin 168.75°$$

$$F_{IR} = -68192\,LB$$

$F_S \cong 0$ (ONLY WHEN [illegible])

$F_S = (5340\text{ LB})(\frac{1}{2}$ [illegible] $25°$

$F_S = 2619\text{ LB}$

[illegible] INSTALLED

CONSIDER FRICTION

ASSUME $\mu_{SLIDING} = \frac{1}{2}\mu$

ASSUME IH CONNECTION IS SLIDING

ASSUME OH CONNECTION IS STICKING

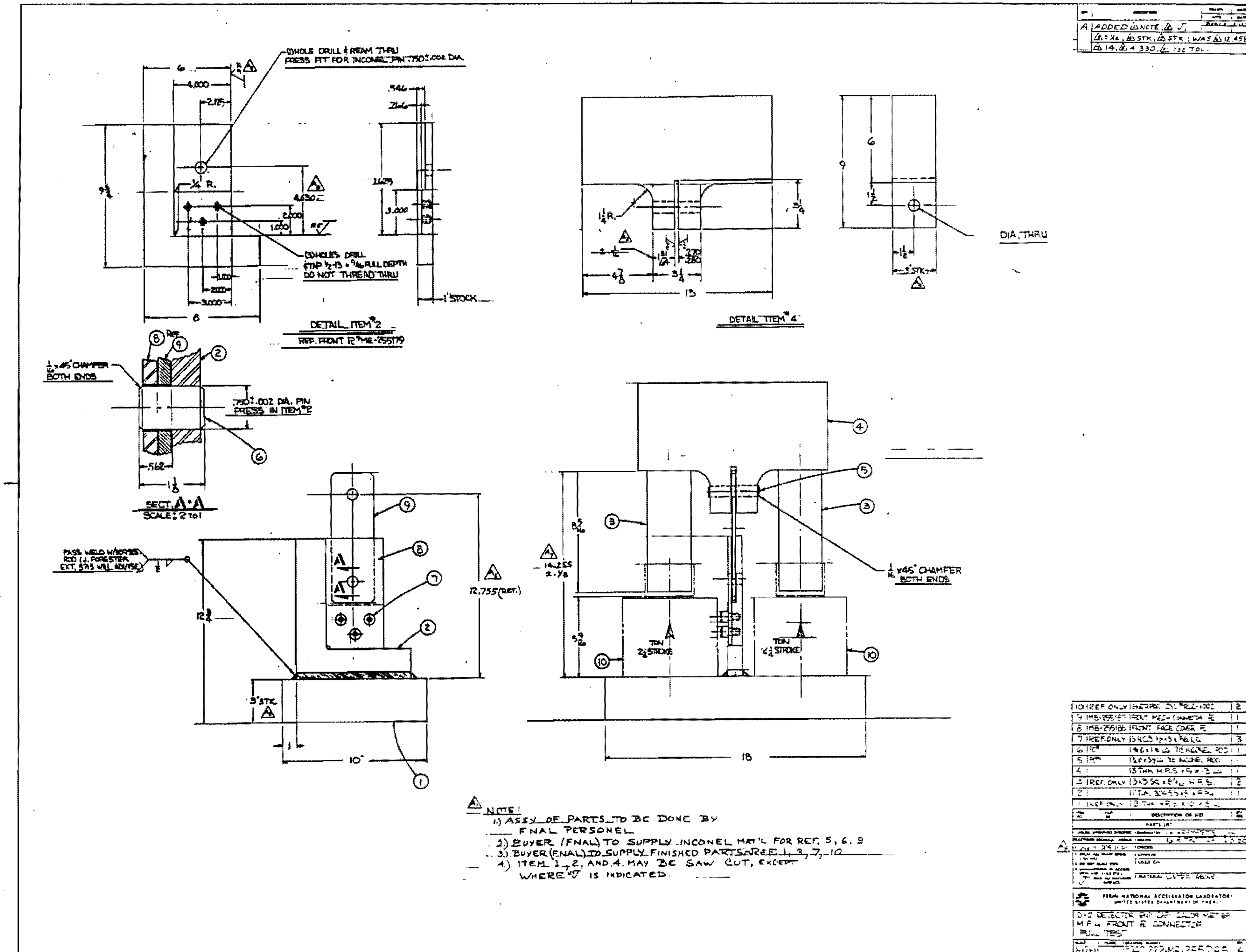
$$\sum M_{IR} = (-21.30'')(18{,}000\text{ LB})(\tfrac{1}{2}\mu) + (-10.31'')(6472\text{ LB})\mu - (24.88'')(F_{OR_f}) = 0$$

$$F_{OR_f} = (19{,}114\text{ LB})\mu$$

$$F_{OR} = (68{,}200\text{ LB}) + (19{,}100\text{ LB})\mu.$$

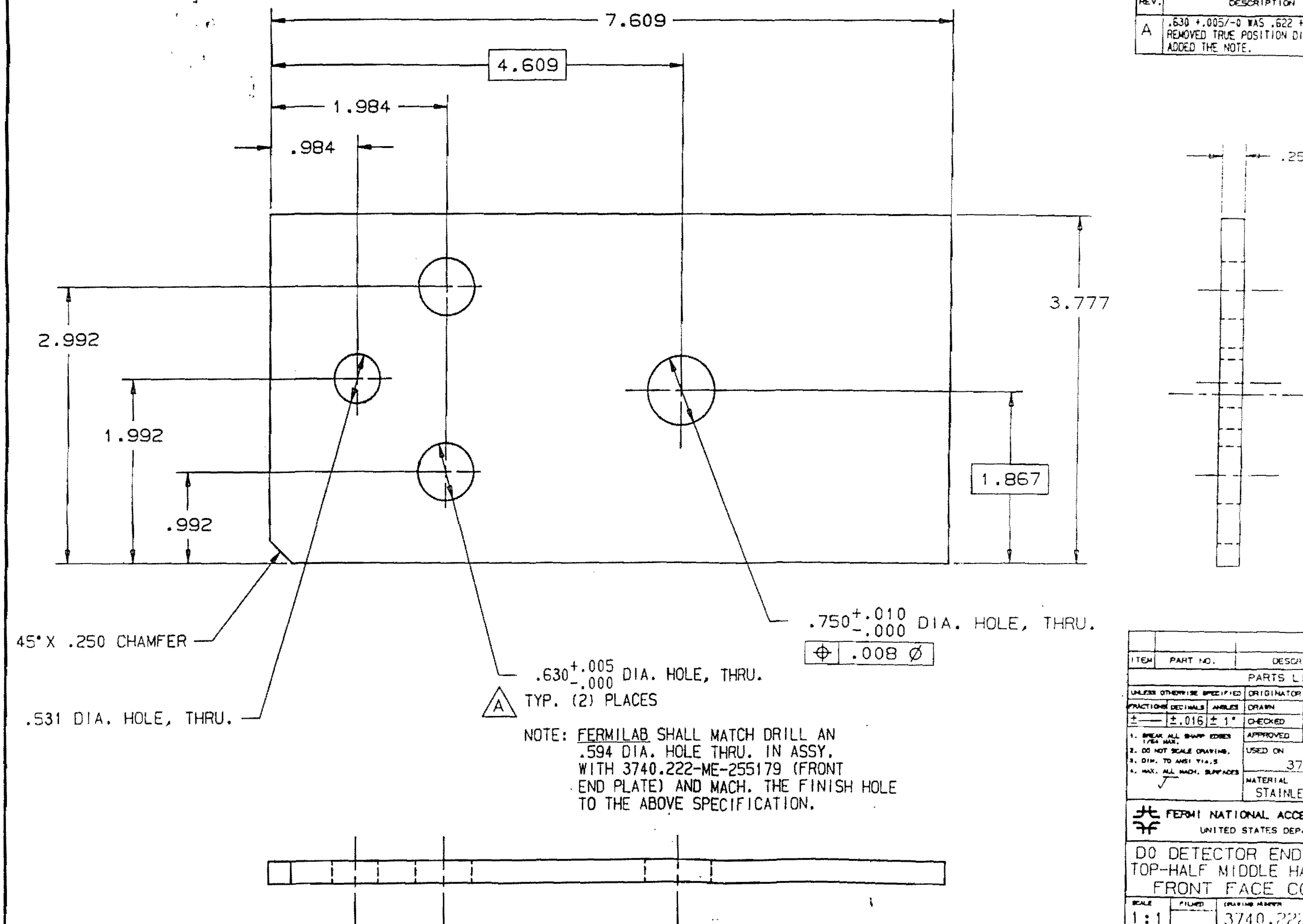
Appendix 2

Drawings



A ADDED NOTE 4 5
(1) HOLE DRILL & REAM THRU PRESS FIT FOR INCONEL PIN .750±.002 DIA.
(3) HOLES DRILL & TAP 1/2-13 x 9/16 FULL DEPTH DO NOT THREAD THRU
1" STOCK
DETAIL ITEM #2
REF. FRONT R.F. ME-255179
DIA. THRU
DETAIL ITEM #4
1/16 x 45° CHAMFER BOTH ENDS
.750±.002 DIA. PIN PRESS IN ITEM #2
SECT. A-A
SCALE: 2 TO 1
PASS WELD W/50PPS ROD (J. FORESTER EXT. 3715 WILL ADVISE)
12.755 (REF.)
14.255 ±.1/8
TON 2 1/2 STROKE
TON 2 1/2 STROKE
1/16 x 45° CHAMFER BOTH ENDS
NOTE:
1.) ASSY OF PARTS TO BE DONE BY FNAL PERSONEL
2.) BUYER (FNAL) TO SUPPLY INCONEL MAT'L FOR REF. 5, 6, 9
3.) BUYER (FNAL) TO SUPPLY FINISHED PARTS REF. 1, 3, 7, 10
4.) ITEM 1, 2, AND 4 MAY BE SAW CUT, EXCEPT WHERE ∇ IS INDICATED.
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

REV.	DESCRIPTION	DRAWN / APPD.	DATE
A	.630 +.005/-0 WAS .622 +0/-.001 AND REMOVED TRUE POSITION DIM. AND ADDED THE NOTE.	S.L.M.	[illegible]



NOTE: FERMILAB SHALL MATCH DRILL AN .594 DIA. HOLE THRU. IN ASSY. WITH 3740.222-ME-255179 (FRONT END PLATE) AND MACH. THE FINISH HOLE TO THE ABOVE SPECIFICATION.

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

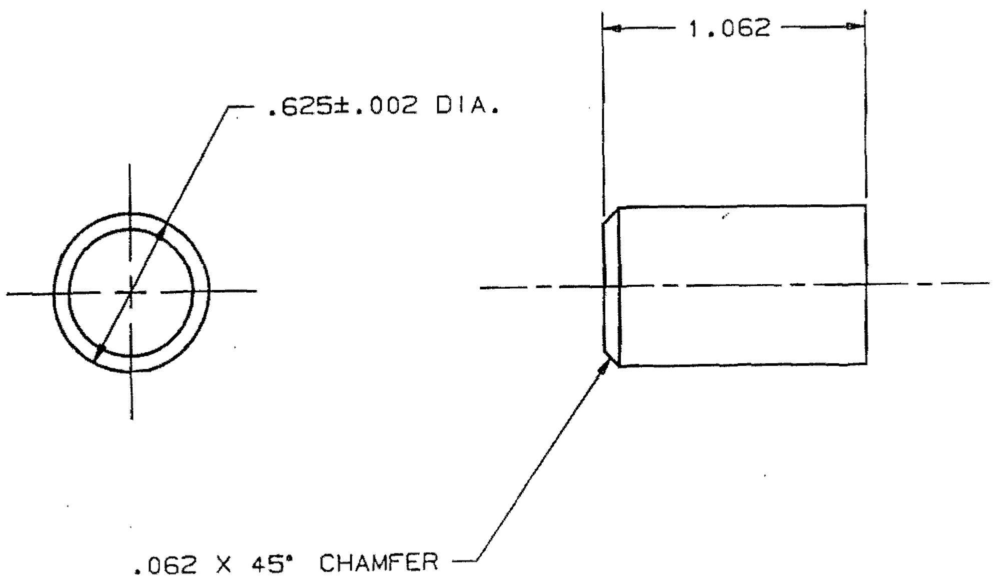
UNLESS OTHERWISE SPECIFIED					
FRACTIONS ± —	DECIMALS ±.016	ANGLES ± 1°	ORIGINATOR	K. KREMPETZ	9-28-88
			DRAWN	S.L. MEREDITH	9-29-88
1. BREAK ALL SHARP EDGES 1/64 MAX.			CHECKED		
2. DO NOT SCALE DRAWING.			APPROVED		
3. DIM. TO ANSI Y14.5			USED ON	3740.222-ME-255186	
4. MAX. ALL MACH. SURFACES √			MATERIAL	STAINLESS STEEL TY-304 PLATE	

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DO DETECTOR END CALORIMETER
TOP-HALF MIDDLE HADRONIC MODULE
FRONT FACE COVER PLATE

SCALE	FILMED	DRAWING NUMBER	REV.
1:1		3740.222-MD-273214	A

CREATED WITH ICEMOON VERSION 1.64



REV.	DESCRIPTION	DRAWN / APPD.	DATE

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTIONS ± —	DECIMALS ±.005	ANGLES ± .5°	ORIGINATOR	K. KREMPETZ	10-4-86
			DRAWN	S.L. MEREDITH	10-4-86
			CHECKED		
			APPROVED		

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRAWING.
3. DIM. TO ANSI Y14.5
4. MAX. ALL MACH. SURFACES √

USED ON 3740.222-ME-255186

MATERIAL INCONEL 718 (AGED HARDEN)

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

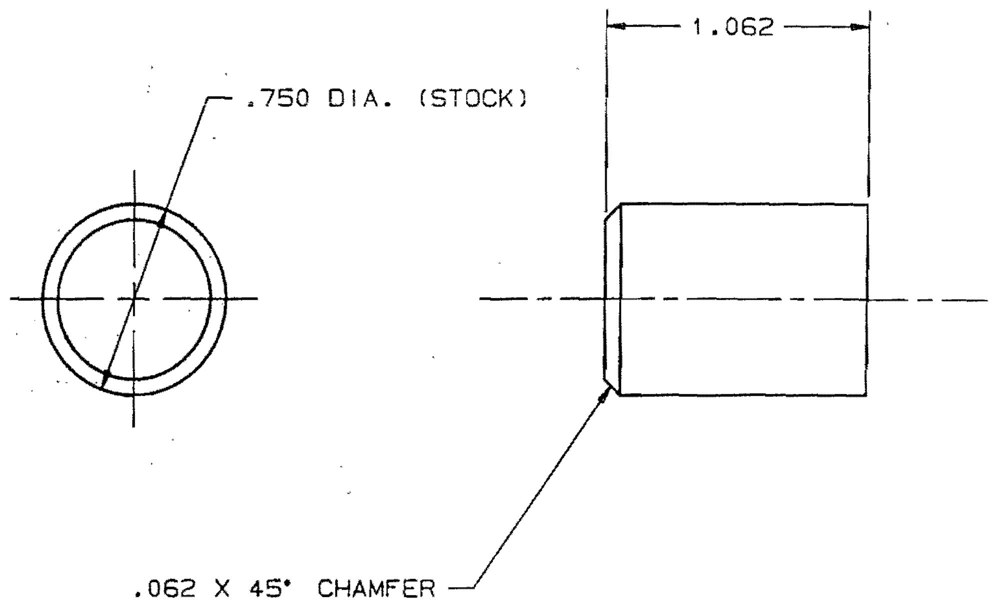
D0 DETECTOR END CALORIMETER
TOP-HALF MIDDLE HADRONIC MODULE
FRONT COVER PLATE PIN DETAIL

SCALE	FILMED	DRAWING NUMBER	REV.
2:1		3740.222-MB-273216	

CREATED WITH ICEMDDN VERSION 1.64

0/04 13.26.54 93642

REV.	DESCRIPTION	DRAWN / APPD.	DATE / DATE



ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	K. KREMPETZ	10-4-88
FRACTIONS	DECIMALS	ANGLES	DRAWN	S.L. MEREDITH	10-4-88
± ——	±.005	± .5°	CHECKED		
			APPROVED		

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRAWING.
3. DIM. TO ANSI Y14.5
4. MAX. ALL MACH. SURFACES √

USED ON 3740.222-ME-255186

MATERIAL INCONEL 718 (AGED HARDEN)

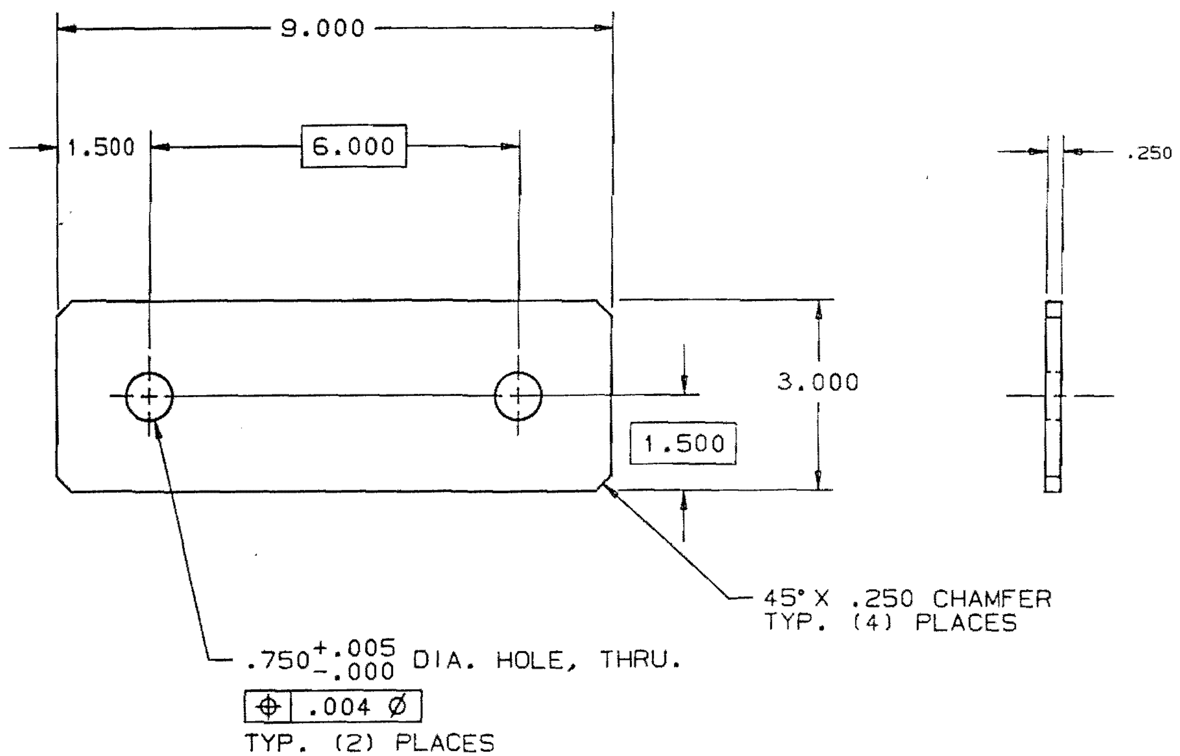
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

D0 DETECTOR END CALORIMETER TOP-HALF MIDDLE HADRONIC MODULE FRONT LINKAGE PIN DETAIL

SCALE	FILMED	DRAWING NUMBER	REV.
2:1		3740.222-MB-273215	

CREATED WITH ICEMDDN VERSION 1.64

10/04 13.14.48 93642



REV.	DESCRIPTION	DRAWN / APPD.	DATE

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTIONS ±	DECIMALS ±.016	ANGLES ± 1°	ORIGINATOR	K. KREMPETZ	9-28-88
			DRAWN	S.L. MEREDITH	9-28-88
			CHECKED		
			APPROVED		

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRAWING.
3. DIM. TO ANSI Y14.5
4. MAX. ALL MACH. SURFACES √

USED ON 3740.220-ME-255181

MATERIAL INCONEL 718

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

D0 DETECTOR END CALORIMETER TOP-HALF MIDDLE HADRONIC MODULE FRONT MECHANICAL LINKAGE PLATE

SCALE	FILMED	DRAWING NUMBER	REV.
1:2		3740.222-MB-273213	

CREATED WITH ICEMDDN VERSION 1.64

'10/04 12.46.33 93642

Appendix 3

Test Data

MH Connector Test, October 24, 1988

Jack Load: 1000 psi 10300 lb

E = 29800000
v = 0.3

	Measured Strains (x10e6)	Adjust for first zero (x10e6)	Adjusted Strain (x10e6)	Stress Intensity (psi)	Max Princ Stress (psi)	Min Princ Stress (psi)	Theta (degrees)	Maximum Shear (psi)	X-Dir Stress (psi)	Y-Dir Stress (psi)	XY Shear (psi)
# 1	436		436								
Front Plate	49		49	13114	13114	140	3.9	6487	13053	201	887
Side, Edge	-18		-18								
# 2	398		398								
Front Plate	28		28	12052	12052	635	0.5	5709	12051	635	93
Side, Center	21		21								
# 3	385		385								
Cover Plate	35		35	11657	11657	575	1.6	5541	11648	584	318
Side, Edge	11		11								
# 4	350		350								
Cover Plate	18		18	10612	10612	599	-0.7	5006	10610	600	-119
Side, Center	27		27								

MH Connector Test, October 24, 1988

Jack Load: 2600 psi 26780 lb

E = 29800000
v = 0.3

	Measured Strains (x10e6)	Adjust for first zero (x10e6)	Adjusted Strain (x10e6)	Stress Intensity (psi)	Max Princ Stress (psi)	Min Princ Stress (psi)	Theta (degrees)	Maximum Shear (psi)	X-Dir Stress (psi)	Y-Dir Stress (psi)	XY Shear (psi)
# 1 Front Plate Side, Edge	1222 158 -54		1222 158 -54	36915	36915	718	4.5	18099	36697	937	2806
# 2 Front Plate Side, Center	1116 94 46		1116 94 46	33821	33821	1826	1.1	15998	33808	1838	635
# 3 Cover Plate Side, Edge	1150 70 25		1150 70 25	34526	34526	808	1.0	16859	34516	819	596
# 4 Cover Plate Side, Center	1063 27 86		1063 27 86	32089	32089	1287	-1.5	15401	32069	1307	-781

MH Connector Test, October 24, 1988

Jack Load: 3800 psi 39140 lb

E = 29800000
v = 0.3

	Measured Strains (x10e6)	Adjust for first zero (x10e6)	Adjusted Strain (x10e6)	Stress Intensity (psi)	Max Princ Stress (psi)	Min Princ Stress (psi)	Theta (degrees)	Maximum Shear (psi)	X-Dir Stress (psi)	Y-Dir Stress (psi)	XY Shear (psi)
# 1	1784		1784								
Front Plate	235		235	53980	53980	1391	4.4	26295	53673	1698	4010
Side, Edge	-68		-68								
# 2	1604		1604								
Front Plate	149		149	48889	48889	3587	0.9	22651	48879	3598	701
Side, Center	96		96								
# 3	1747		1747								
Cover Plate	128		128	52475	52475	1194	1.7	25640	52432	1237	1482
Side, Edge	16		16								
# 4	1612		1612								
Cover Plate	38		38	48505	48505	1473	-1.2	23516	48486	1493	-966
Side, Center	111		111								