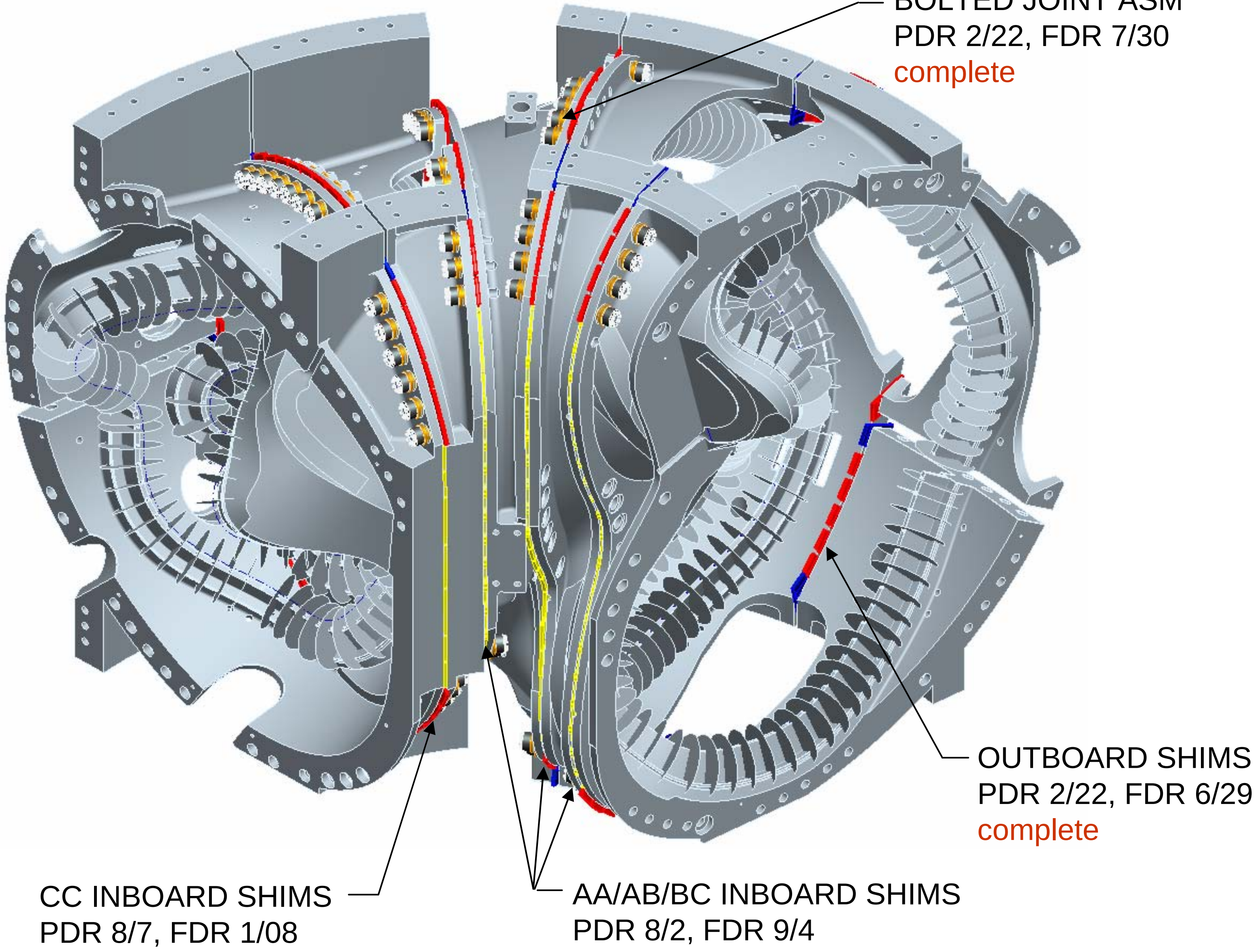
Modular Coil Interface Hardware C-C Inboard Shims PDR

Presented by
P Fogarty, K Freudenberg, D Williamson
August 7, 2007

Review Charge

- Are the requirements defined? What is the proposed design?
- What is the status of mockup / access studies?
- Is the analysis consistent with proposed design?
- Have prior design review chits been addressed?
- Have all technical, cost, schedule, and safety risks been addressed?

Scope


BOLTED JOINT ASM
PDR 2/22, FDR 7/30
complete
OUTBOARD SHIMS
PDR 2/22, FDR 6/29
complete
CC INBOARD SHIMS
PDR 8/7, FDR 1/08
AA/AB/BC INBOARD SHIMS
PDR 8/2, FDR 9/4

Requirements are derived from the Modular Coil Asm Specification (NCSX-CSPEC-14-05-01) and the Station-2 Asm Specification (in progress).

Electrical

- Partial Toroidal electrical breaks shall be provided between adjacent modular coils within a field period (AA, AB, BC).
- Electrical breaks are required between adjacent modular coils in adjacent field periods (CC). [Ref. GRD Section 3.2.1.5.2b to be revised]
- Toroidal electrical breaks must be able to withstand an applied voltage of 150 V (ref. GRD Section 3.2.1.5.3.6).

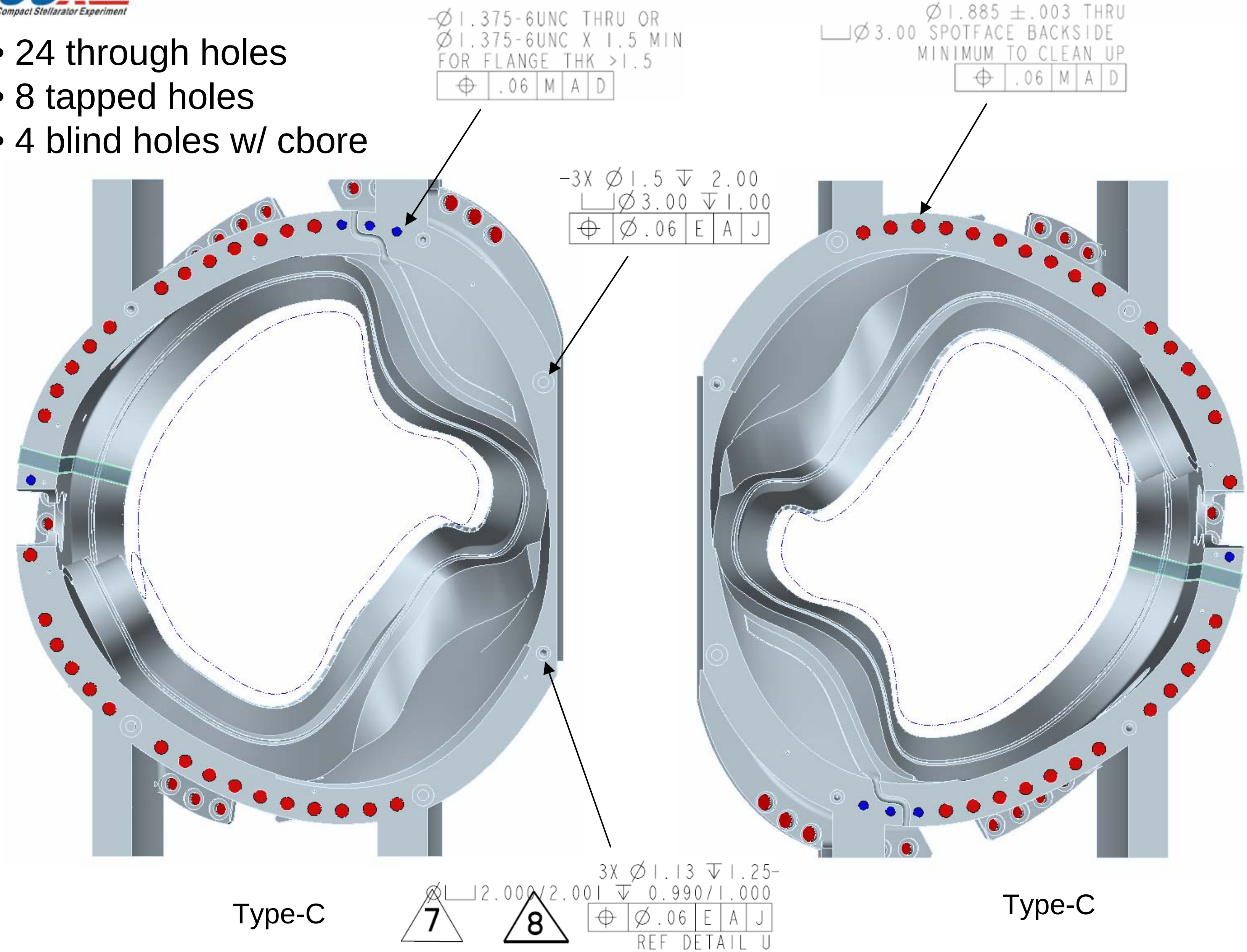
Structural

- Carry loads up to 15-ksi compression, 4-kip/in shear
- Maintain a “no slip condition” under the bolts (friction joint)

Assembly

- Position the coils accurately
- Minimize gaps

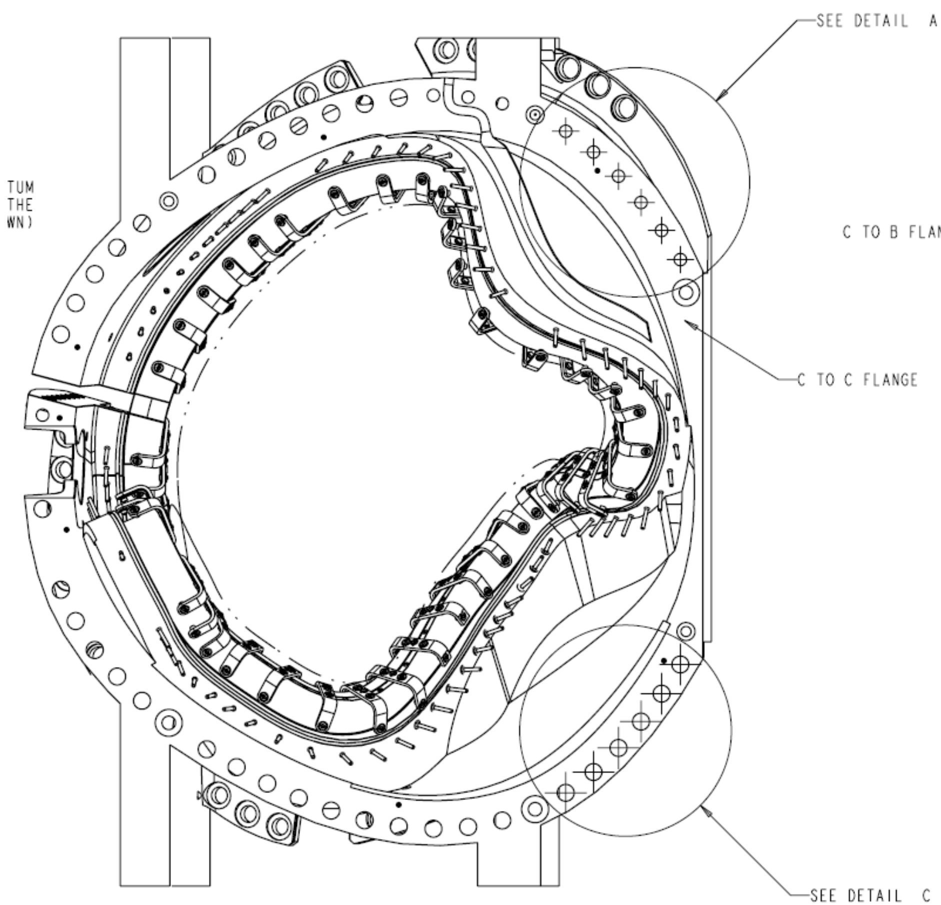
- 24 through holes
- 8 tapped holes
- 4 blind holes w/ cbore

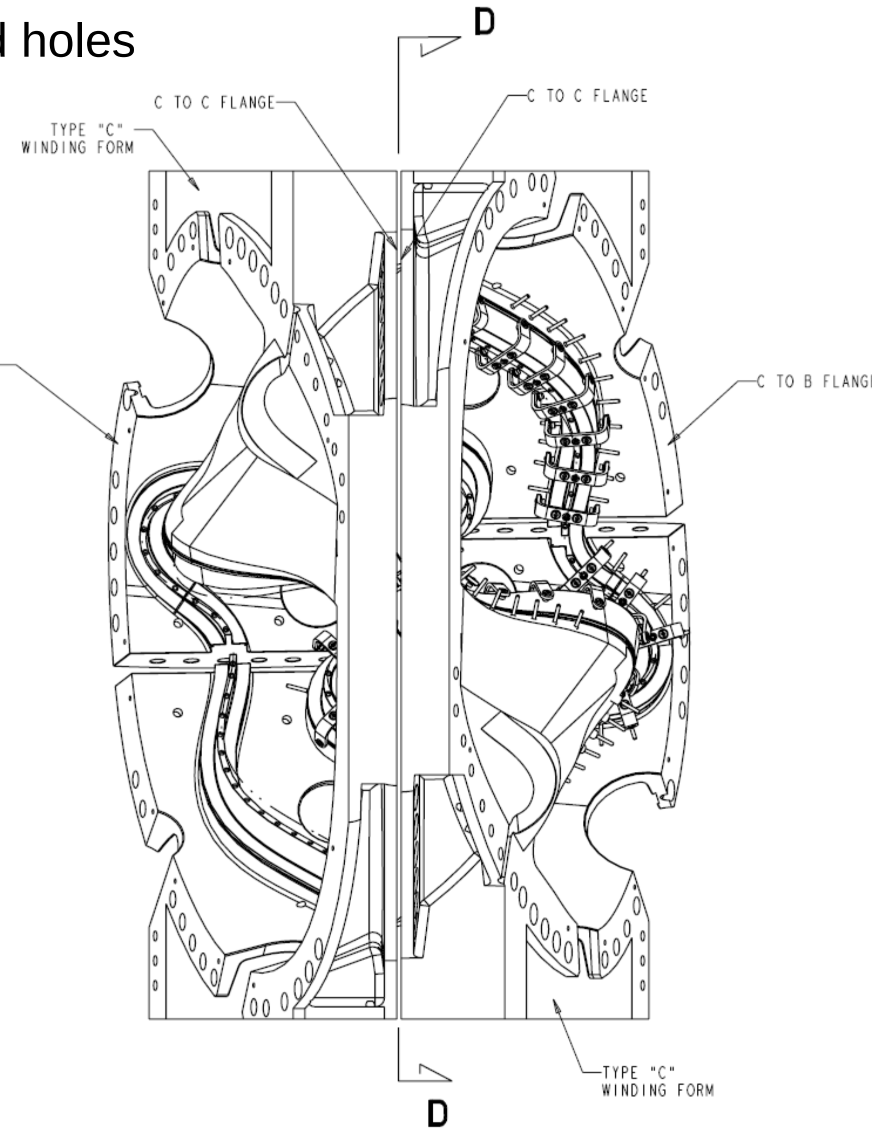


Type-C

Type-C

- SE141-148 defines 12 additional inboard holes



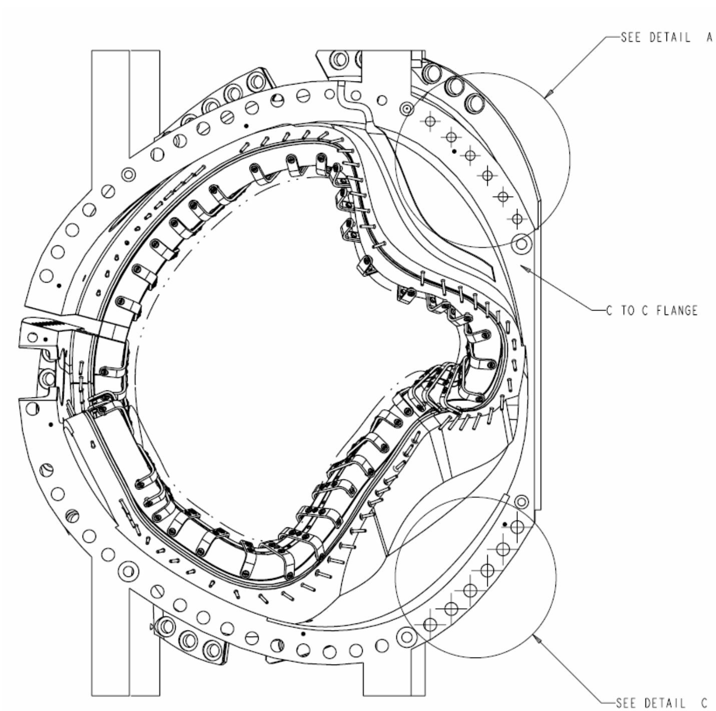


VIEW D - D
TYPE C WINDING FORM VIEW OF C-C FLANGE, DATUM E
MAY BE PART ONLY OR PARTIALLY ASSEMBLIED
SCALE 0.12

Hole specification:

⌀1.375-6UNC THRU OR
⌀1.375-6UNC X 1.5 MIN
FOR FLANGE THK >1.5

⌀1.885 ±.003 THRU
⌴⌀3.00 SPOTFACE BACKSIDE
MINIMUM TO CLEAN UP



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TYPE C WINDING FORM VIEW OF C-C FLANGE, DATUM E
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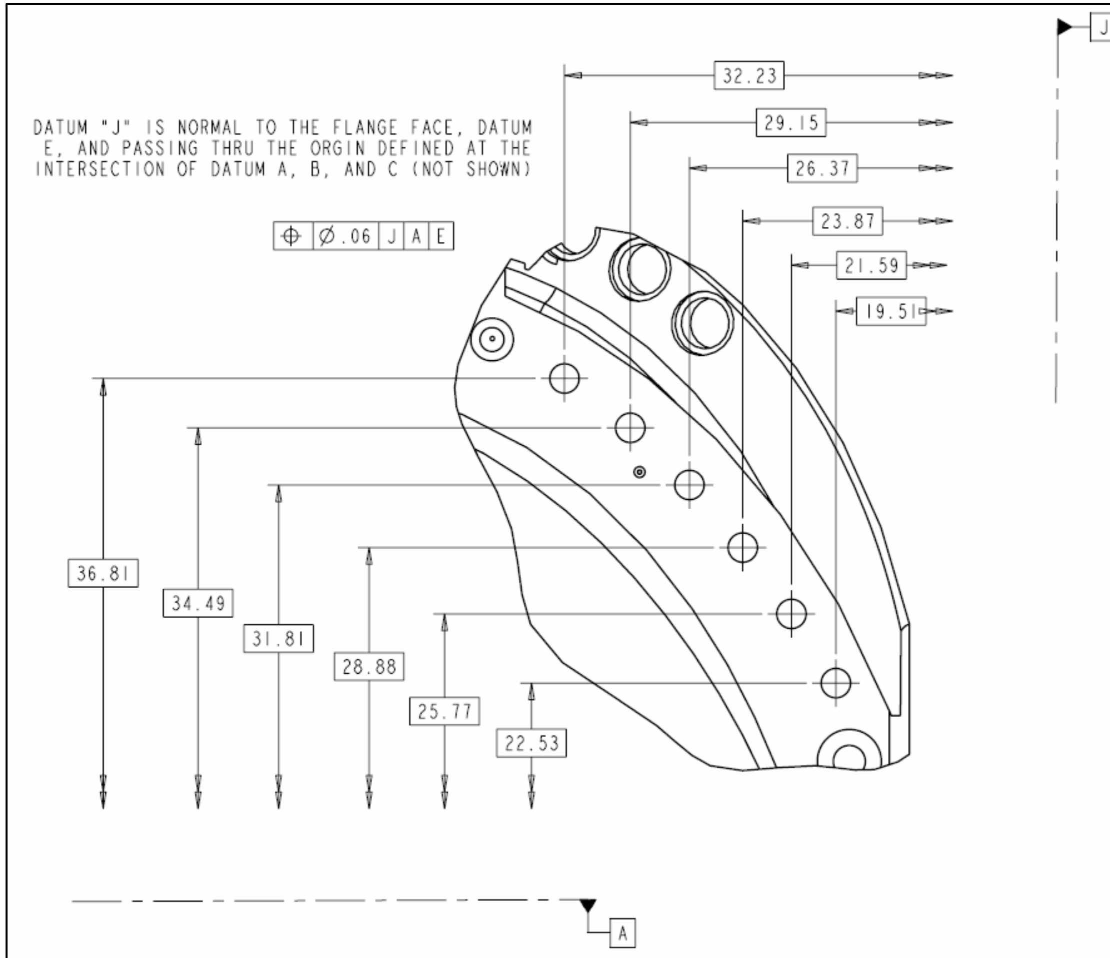
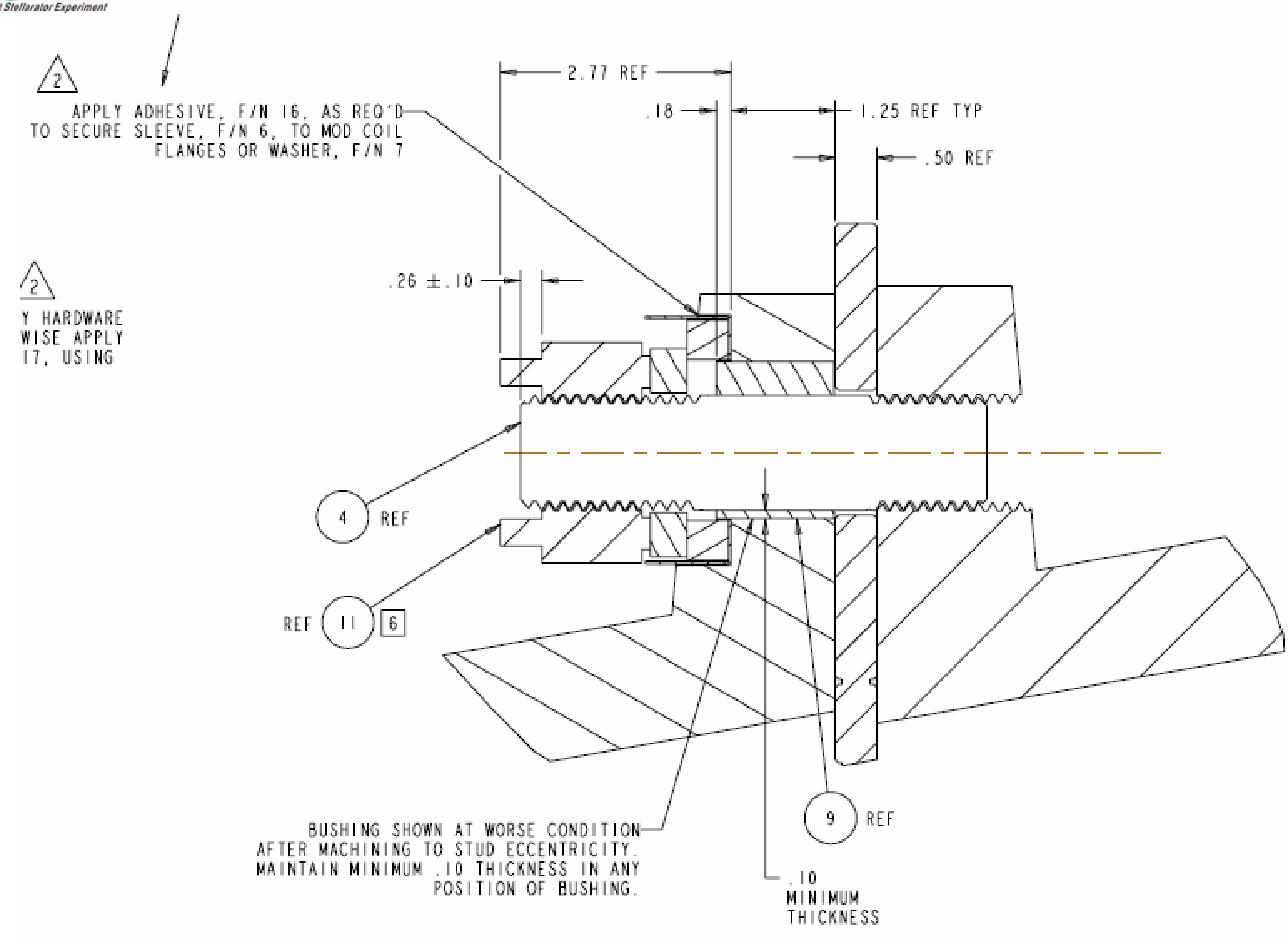
SCALE 0.12



DETAIL A
SCALE 0.240

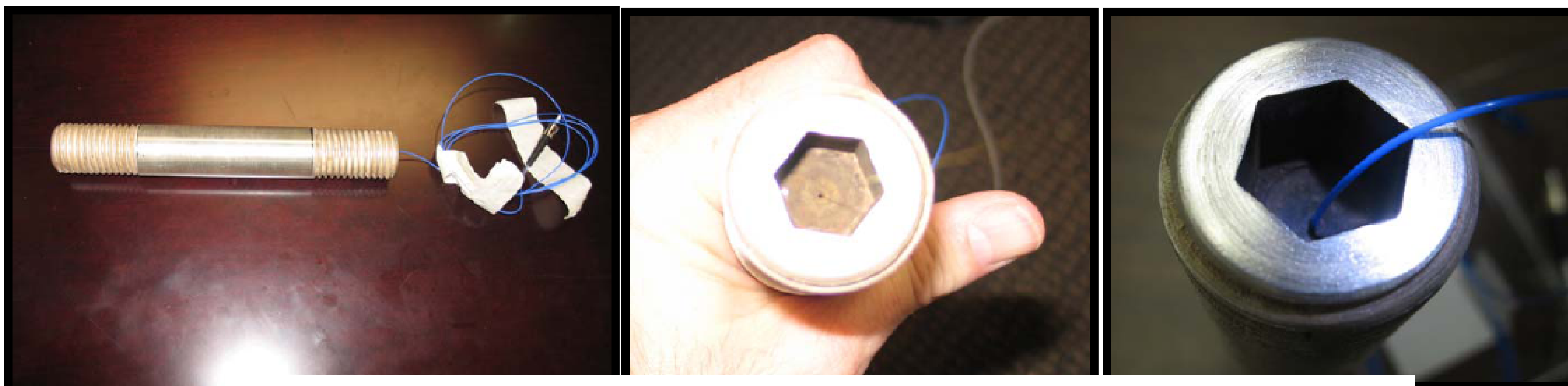
Bolted Joint Asm (SE140-190-R2)



TAPPED BOLT SECTION
SCALE 1.00

Bolted Joint Asm (SE140-190-R2)

- Fiber-optic strain gages used to check analysis, monitor changes in performance
  - Gages unaffected by magnetic field, need no additional electrical isolation
  - Significant testing indicates some scatter on absolute measurements but very good repeatability over many cycles, at LN2 temperature
  - Gages can be installed in studs (.02 hole EDM-ed) and calibrated to provide very accurate indication of stud preload during operation



Trial installation of fiber optic gage in 1.375 dia stud

C-C FLANGE SHIM LAYOUT

CC Hole #	Shim Length Hole to Bottom	No Bolt Shim
1	2.75	
2	2.75	
3	2.75	
4	2.75	
5	2.75	
6	2.75	
7		2.75
8	2.75	
9	2.75	
10	2.75	
11	2.75	
12	2.75	
13	5.00	
14	5.00	
15	3.75	
16	3.75	
17	5.00	
18		5.00
19	3.75	
20	3.75	
21	3.75	
22	3.75	
23	3.75	
24		3.75
25	5.00	
26	5.00	
27		3.75
28	3.75	
29	3.75	
30	3.75	
31	3.75	
32	3.75	
33		5.00
34	5.00	
35	3.75	
36	3.75	
37	5.00	
38	5.00	
39	2.75	
40	2.75	
41	2.75	
42	2.75	
43	2.75	
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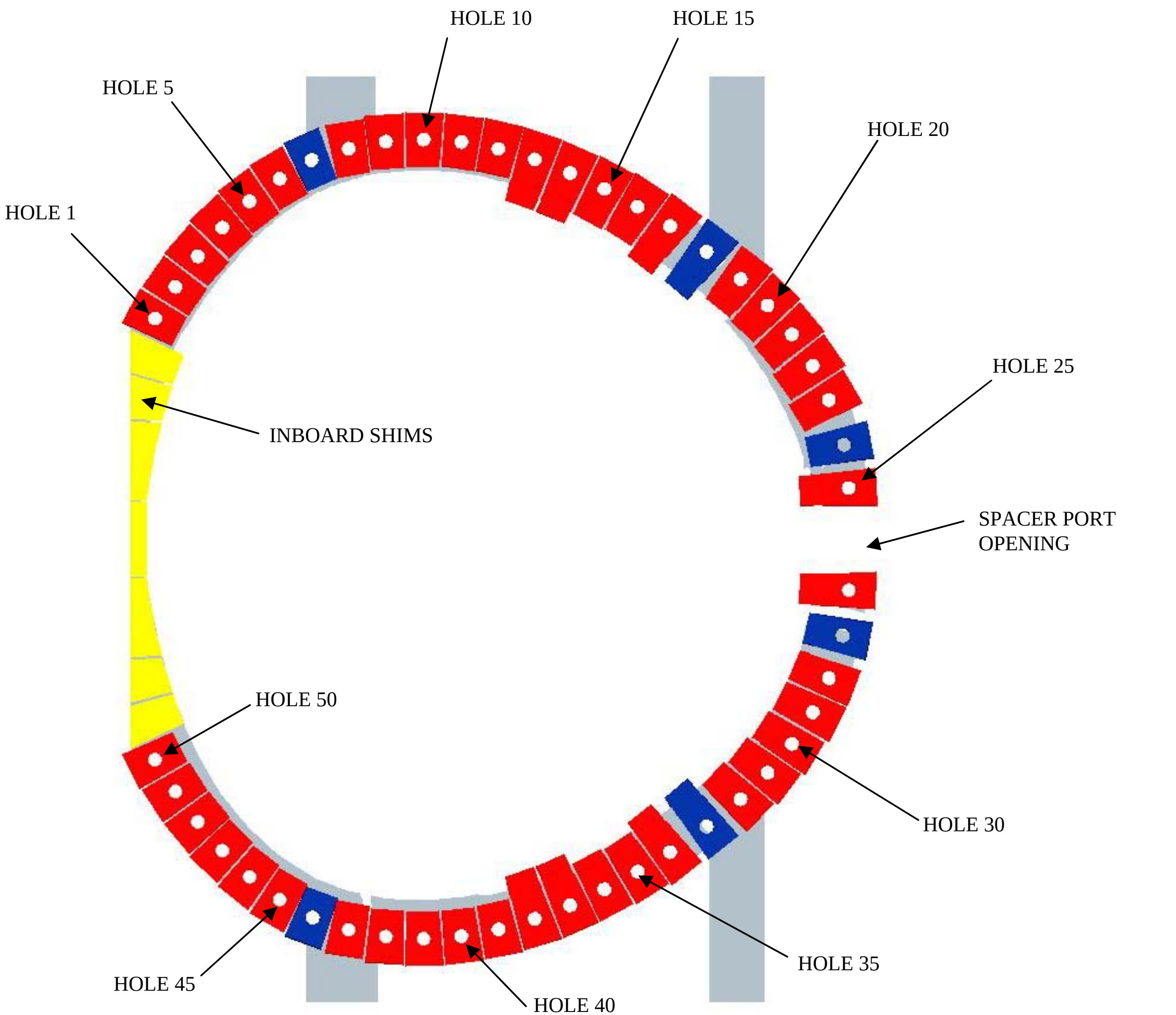
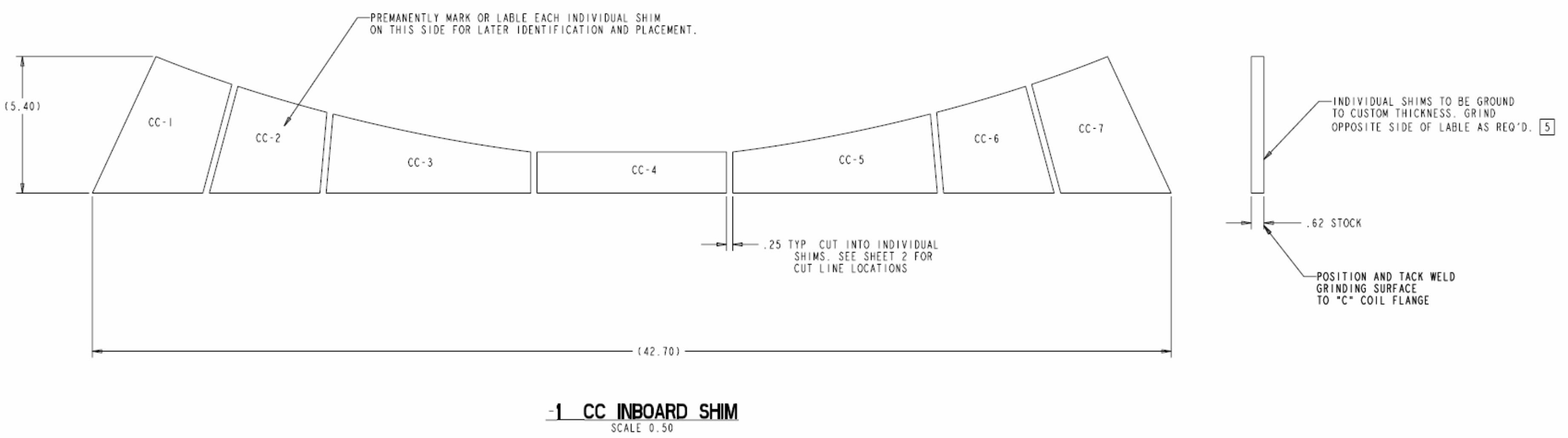
47	2.75	
48	2.75	
49	2.75	
50	2.75	



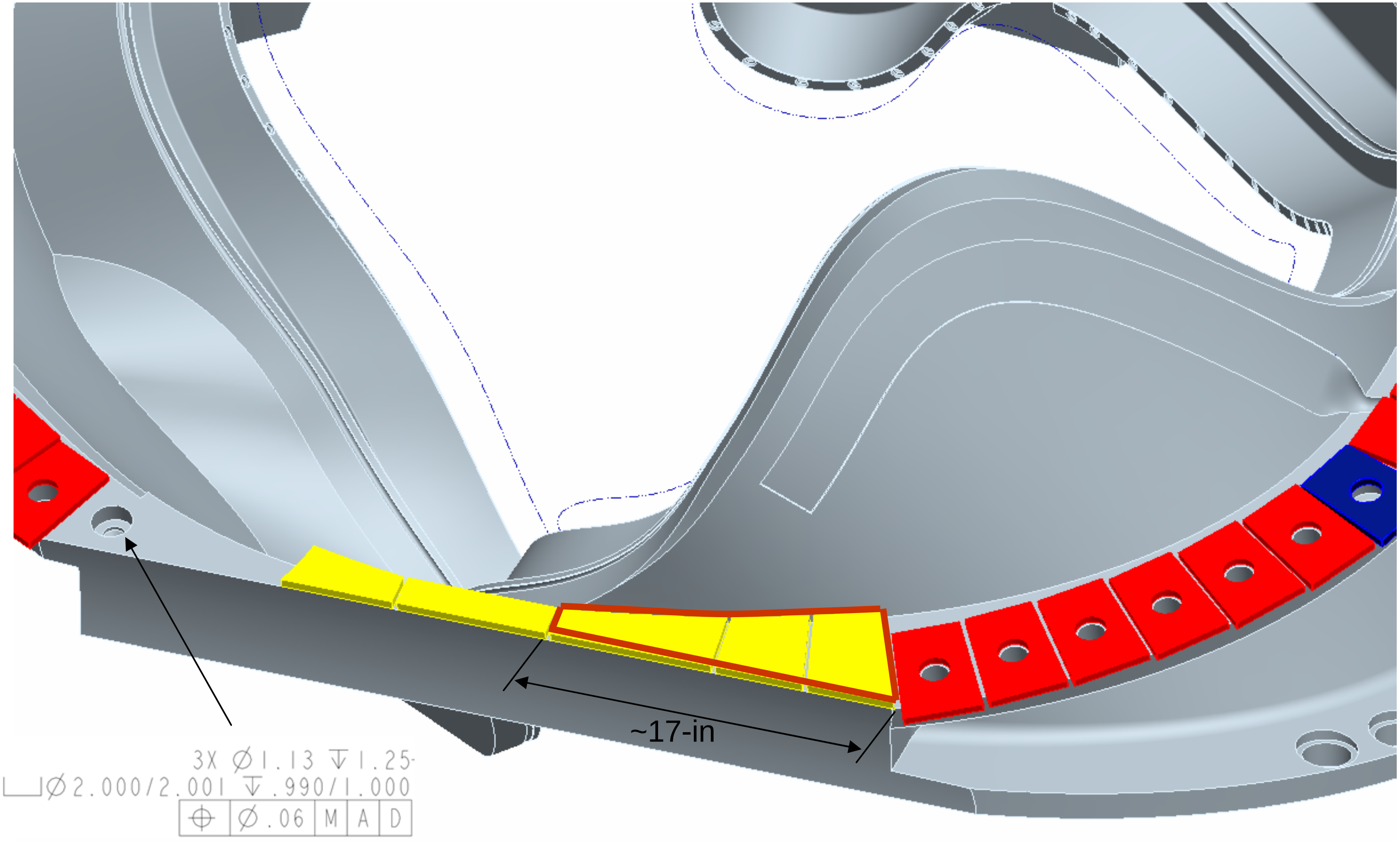
Inboard Shims

- Drawing SE140-055 defines inboard compression shims template
- Insulated, weld to flange one side



Inboard Shims

- Optional concept reduces no. shims, uses spherical seat feature



Mockup / Access Studies

Development activities conducted at UT Magnet Development Lab (MDL):

- Mock-up construction
- Weld access for AA/AB/BC
- Access studies for CC

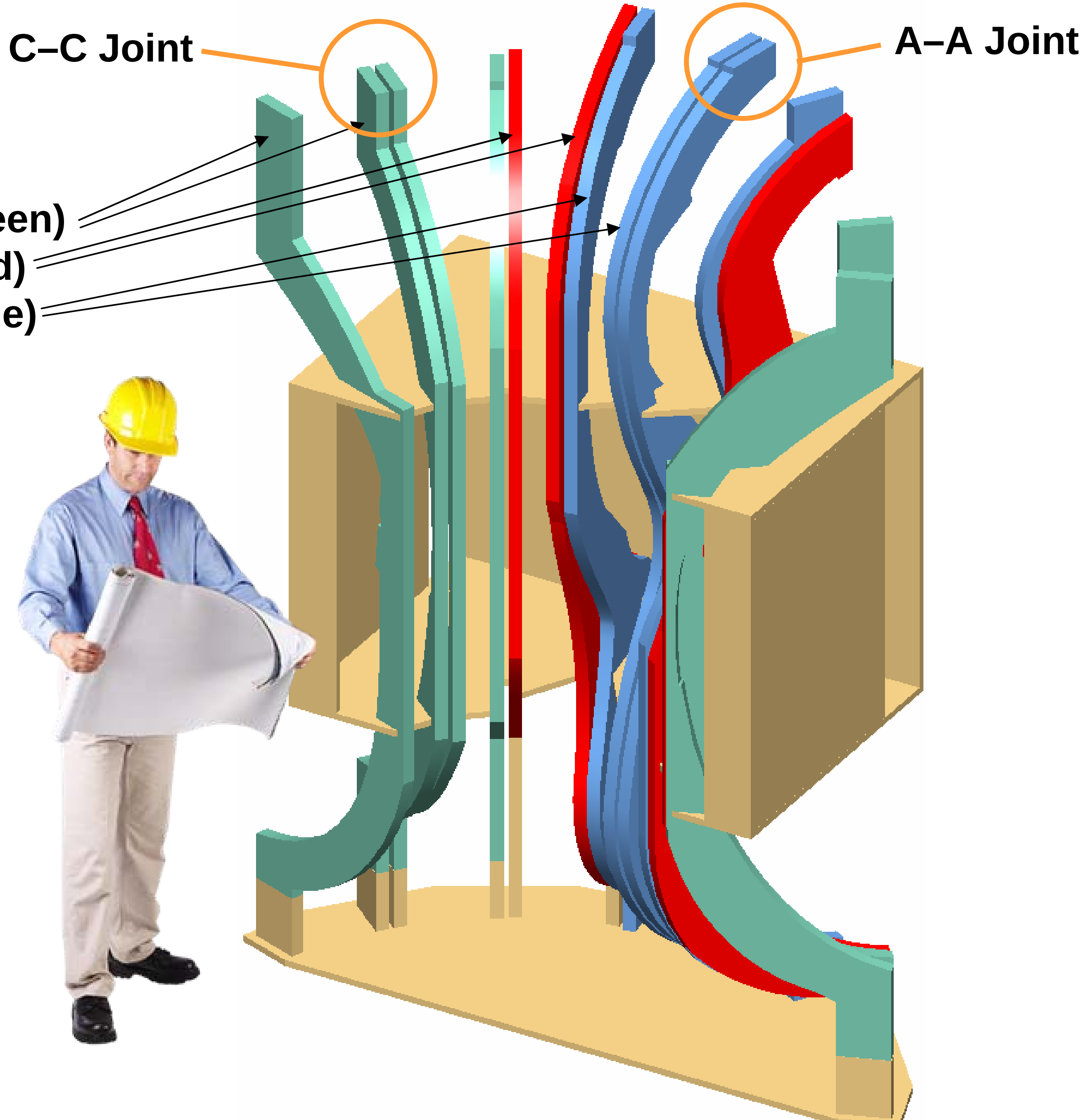
The Design:

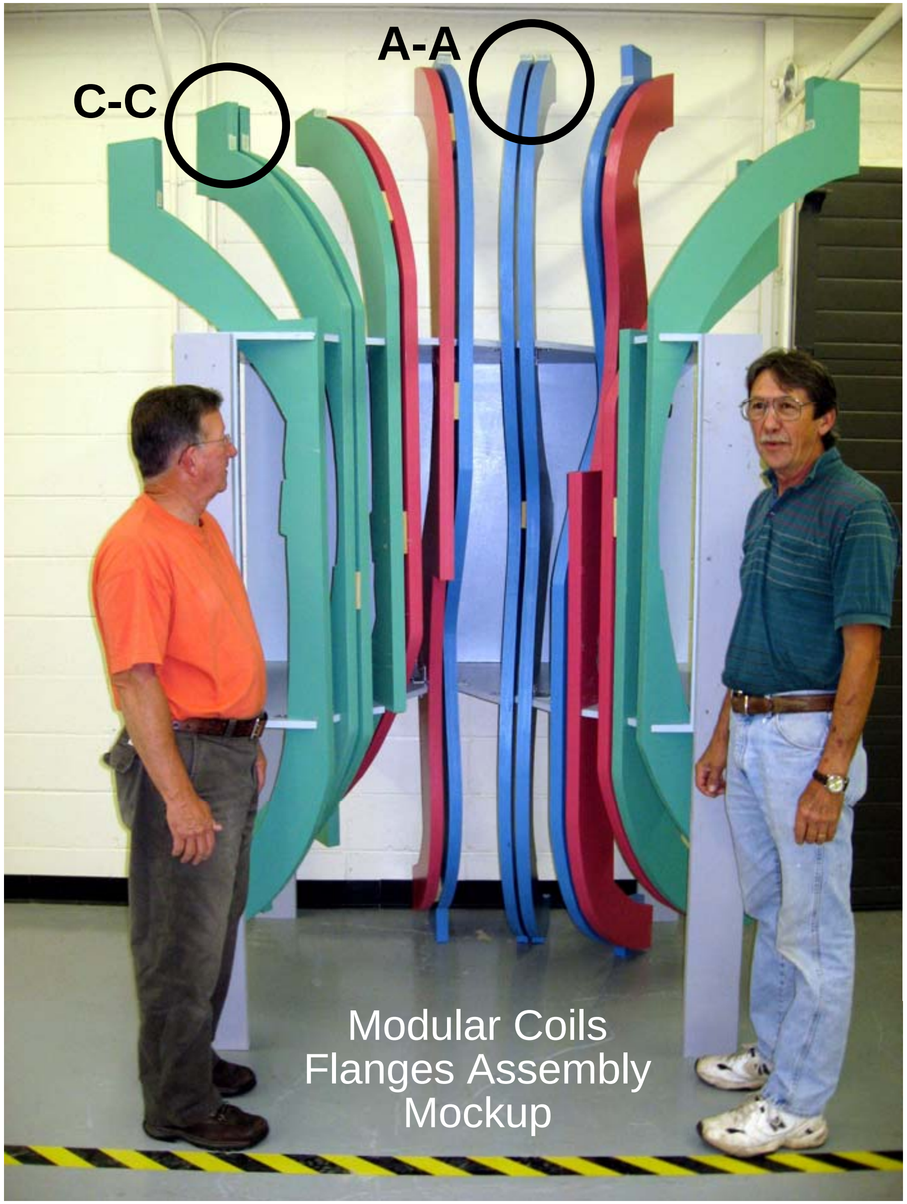
- Totally bolted, electrically isolated
- 6 top and 6 bottom inboard flange holes, with tapped holes in one flange and a thru holes in mating flange
- “Reasonably” tight fitting bushings
- Nut options: Superbolt, Hex, Hydraulic Nut w/ lock nut

Design Issues:

- Physical **ACCESS**
  - Initial installation of bolting hardware
  - Re-Torquing of nuts (for all flange interfaces)
- Choice of ACCESS location
  - Top and bottom, inboard, between TF coils
  - Top and bottom, outboard, at “B” coil
  - Top and bottom, outboard, thru back of “C” coil
- Risks associated with ACCESS location
- Measuring and installing bushings

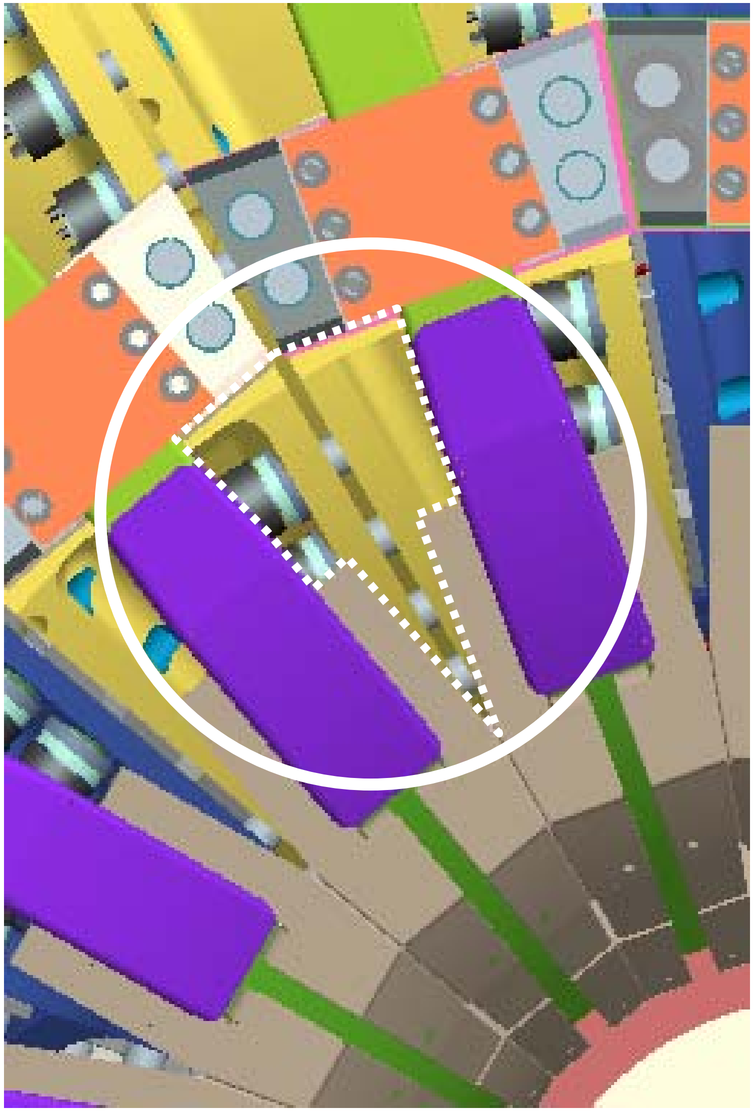
Field Period In-board Flanges Mockup
(Including C - C)

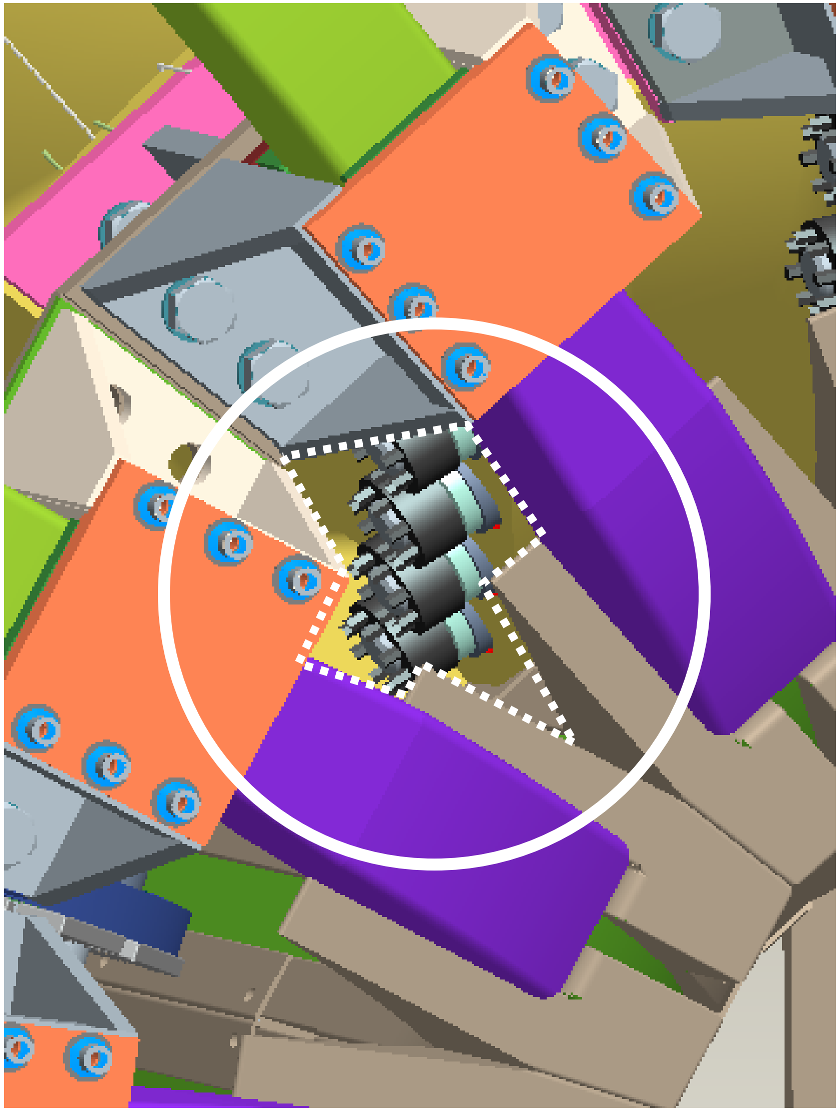



A-A
C-C
Modular Coils
Flanges Assembly
Mockup


Checking access
for welding

Top and bottom, inboard between TF coils:





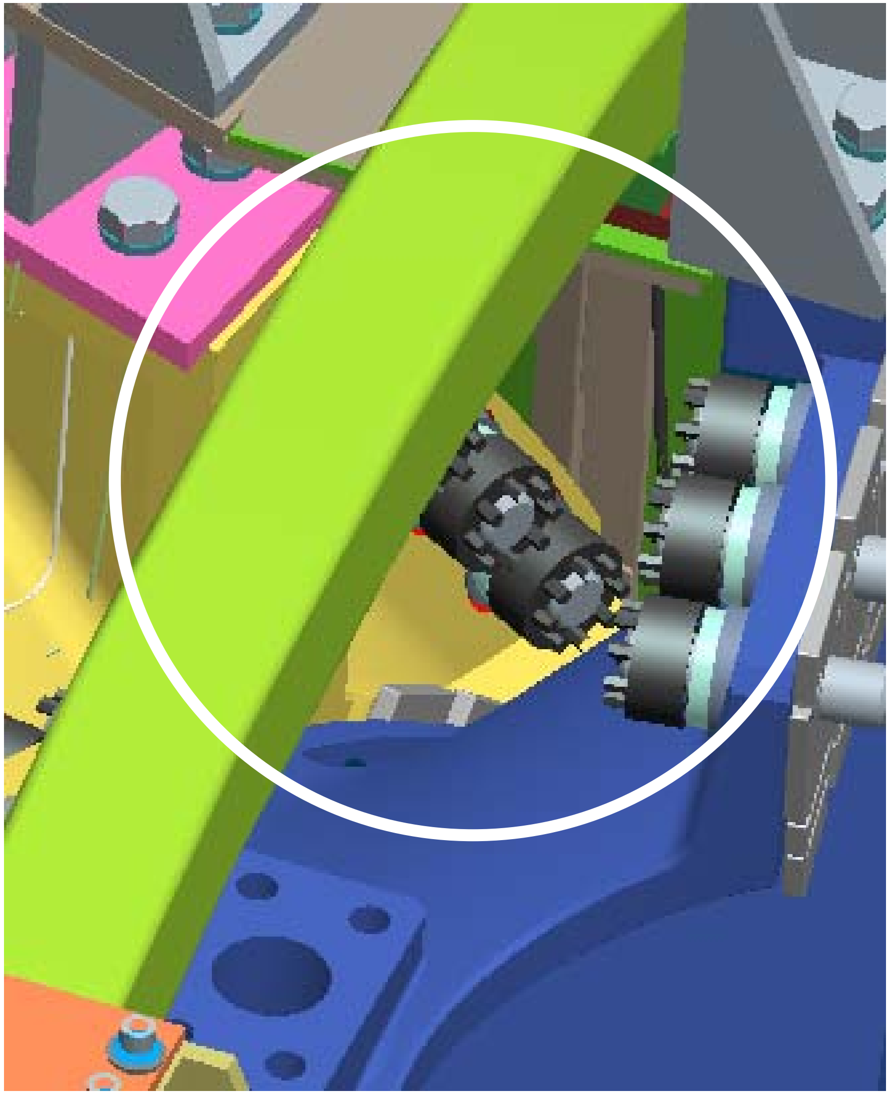
NCSX National Compact Stellarator Experiment

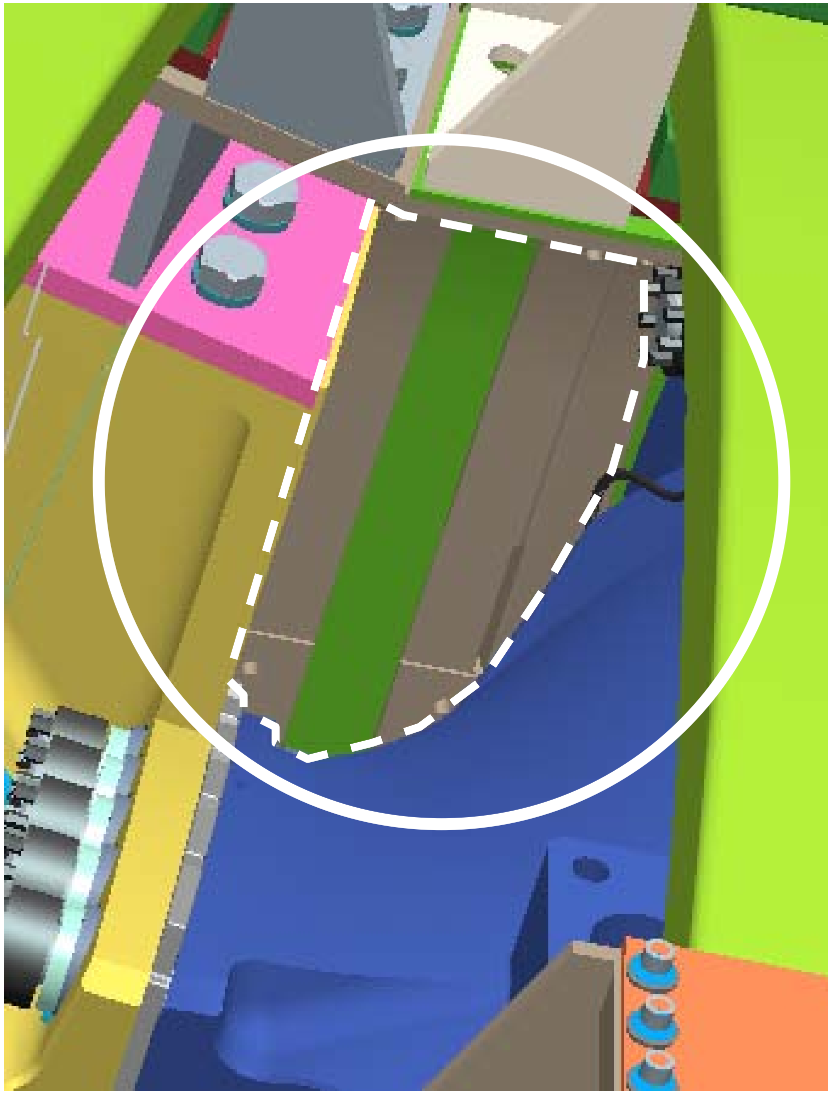
Top and bottom, inboard between TF coils:

- Visually clear line of sight, directly above and between TF openings on either side
- Easiest access and most comfortable working position
- Lowest risk of a worker damaging any external tubing, headers, electrical hardware, etc…
- Longest distance to reach the bottom-most nut
- Access opening is more restricted

C – C Interface

Top and bottom, outboard at “B” coil:





Top and bottom, outboard thru back of "B" coil:

- Most direct access to nuts
- Shortest distance to reach the bottom-most nut (19"), good possibility of a worker (small in stature, with long arms) being able to use a hands-on approach when installing bolt kit
- High risk of a worker damaging some of the external tubing, headers, electrical hardware, etc… by having to climb around the shell and lay horizontally and try to wedge down into the opening
- Does not allow a direct line of sight for worker, video camera / light system will be needed

NCSX National Compact Stellarator Experiment

Measuring, fabricating, installing bushings:

- A video system (flexible cable) with lighting will be needed to read the bushing gage for measuring hole eccentricity

- An alternative is to wrap the outer gage surface with litmus or fuji paper so when the gage rotates and stops, a line marks where it touches the hole inner diameter

- The finished bushing:
  - Slides down the strain gage sheathing onto stud
  - Is oriented accurately to the hole
  - Slightly inserted into flange hole
  - Bearing washer, hex nut slides down cable
  - Nut is tightened to press the bushing into hole

- Bushing installation nut is removed, permanent nut is re-installed with complete washer set

Proposed R&D:

Prove feasibility of making and installing a bushing	Design, develop, and acquire necessary tools and hardware – identify and acquire necessary video / lighting components	Field test tooling, video equip to make and install bushings
← 1 Month →	← 2 Months →	← 1 Month →

Manpower – PJ (.5), Gary (.25-.5), Joe (.25), Jim (.25), Bob (.25) = 1.5 – 1.75 for 4 months

- Feasibility study will be to measure and install a bushing in an enclosed "box" using manipulator, video camera mounted in side and light inside.
  - Determine most accurate method of measuring bushings
  - Determine how to orient / register bushing with hole
  - Determine if bushing can be "seated" using a nut
- Design and development stage will involve:
  - Manipulator fabrication or modifications
  - designing controls for moving, rotating, etc… video system
- Field testing ideally involves using a C-C assembly in a vertical position with a B coil to see if there are any surprises due to mistakes in the coil castings - and also using the "actual", out-of-round flange holes

NCSX National Compact Stellarator Experiment

Conclusions:

- Based on the design of 6 top and 6 bottom holes, 4 of the 6 holes appear to be accessible for making tight fitting bushings and bolting the joint with a reasonable effort.
- 2 of the 6 holes will require a difficult and time consuming effort to accomplish the bolted design.
- R&D tasks have been identified and planned to insure the success of the bolted design.
- Bottom Line: It is feasible to make the bolted C-C joint

Inboard interface FEA model developed for different C-C options:

- Six or twelve additional bolts
- 1.375 or 1.5-in diam bolts

Options to restrain movement of inboard leg.

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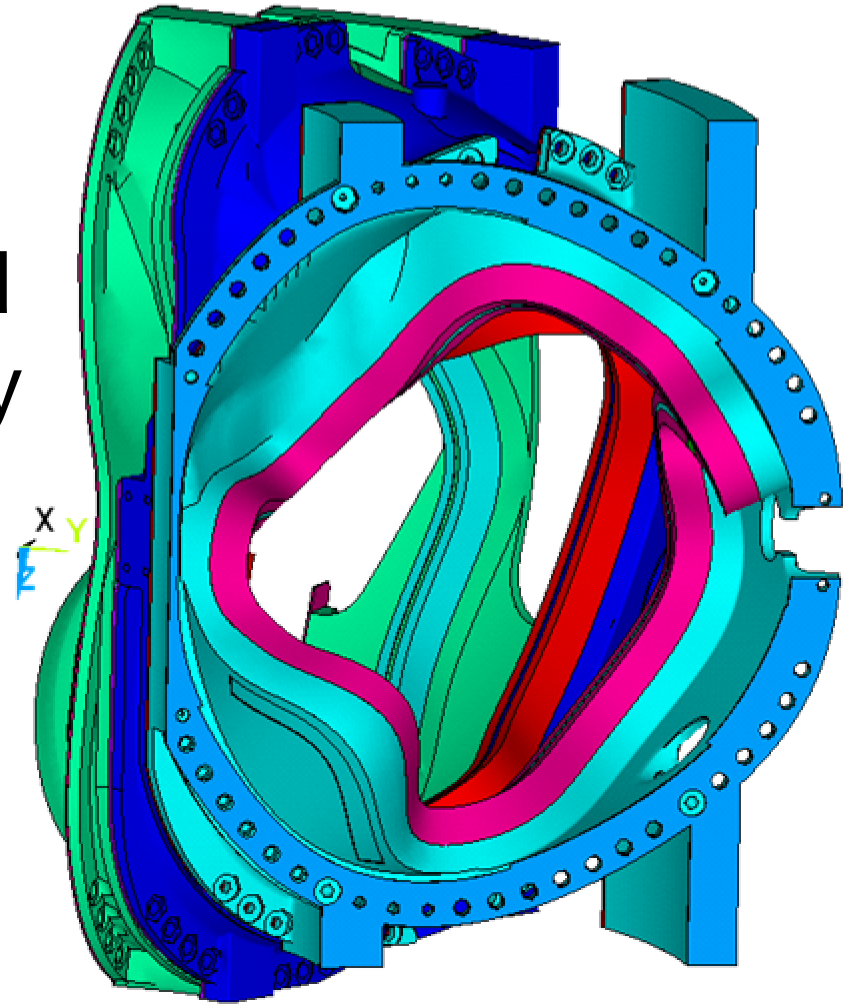
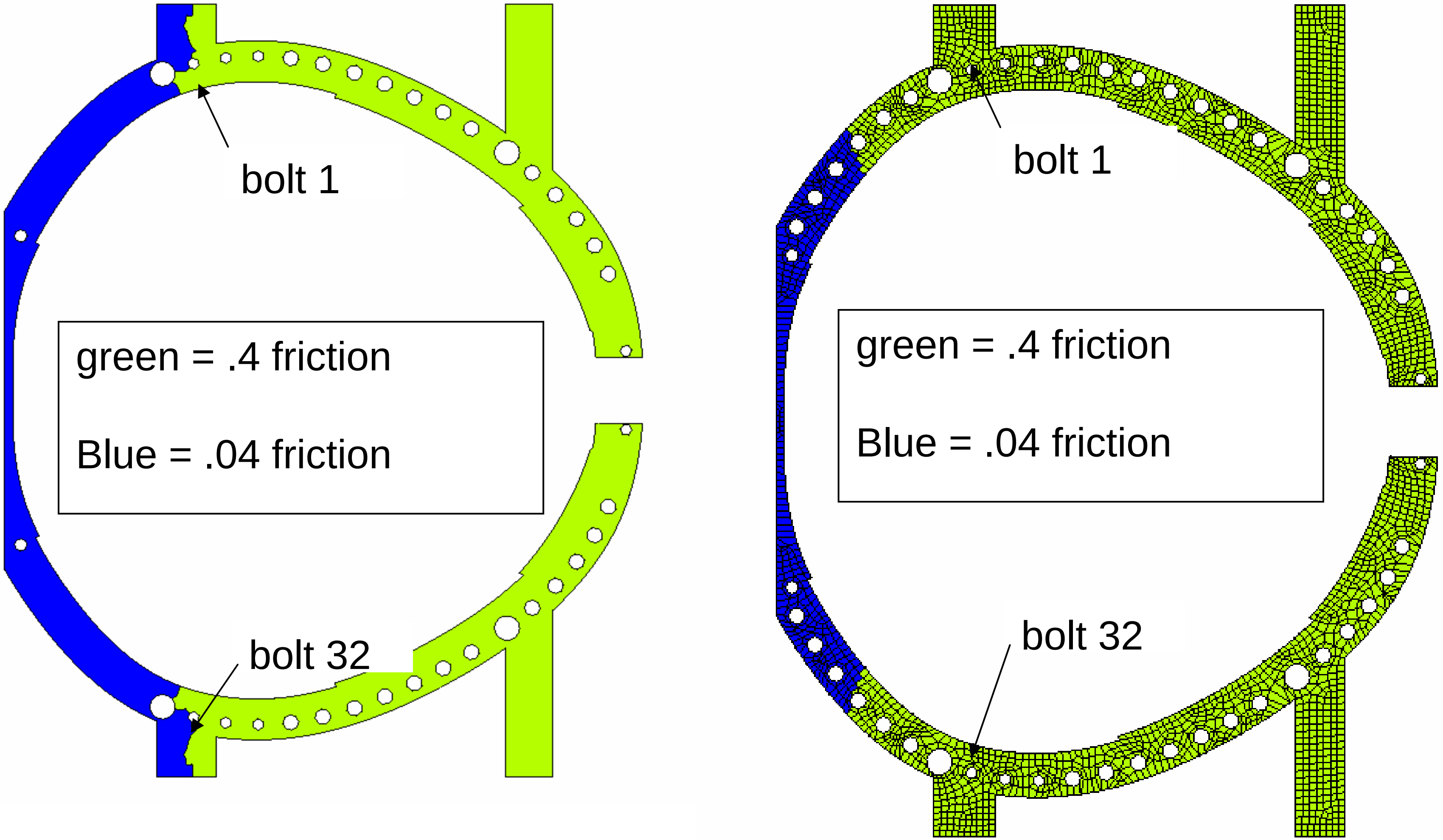
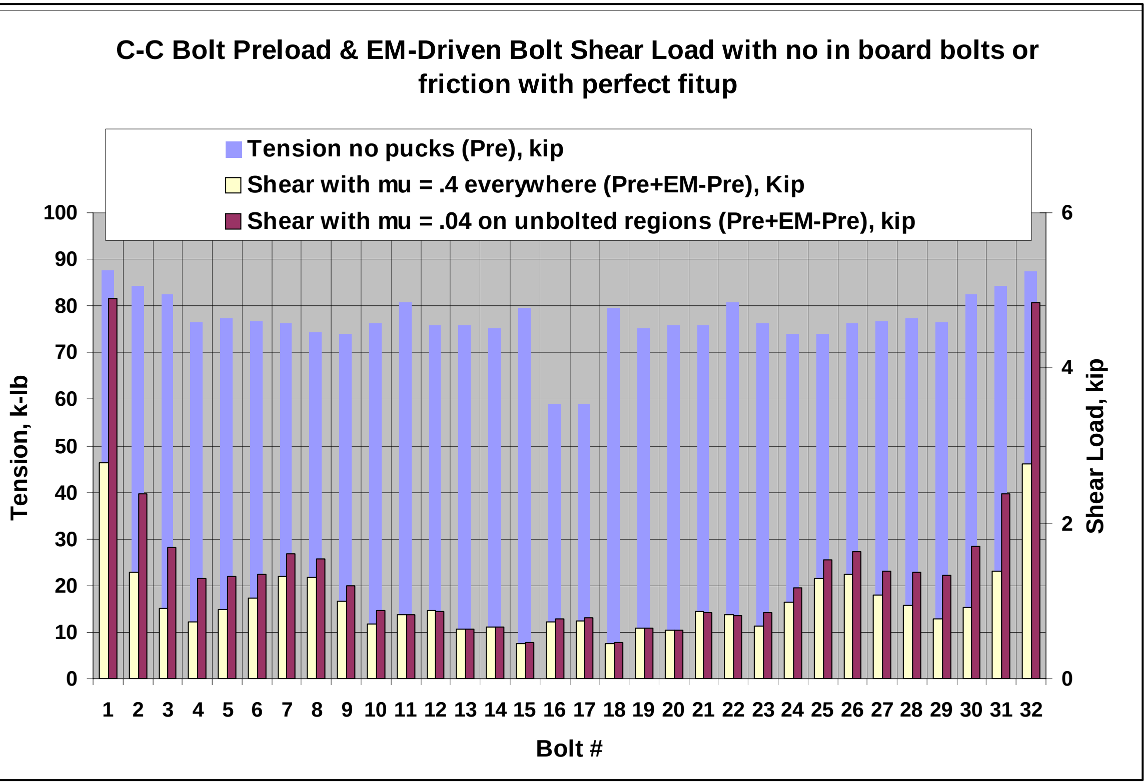
- By adding 6 to 12 bolts on the inner leg, the inner leg motion should be reduced significantly
- (model on right has 12 bolts added north and south of the midplane.

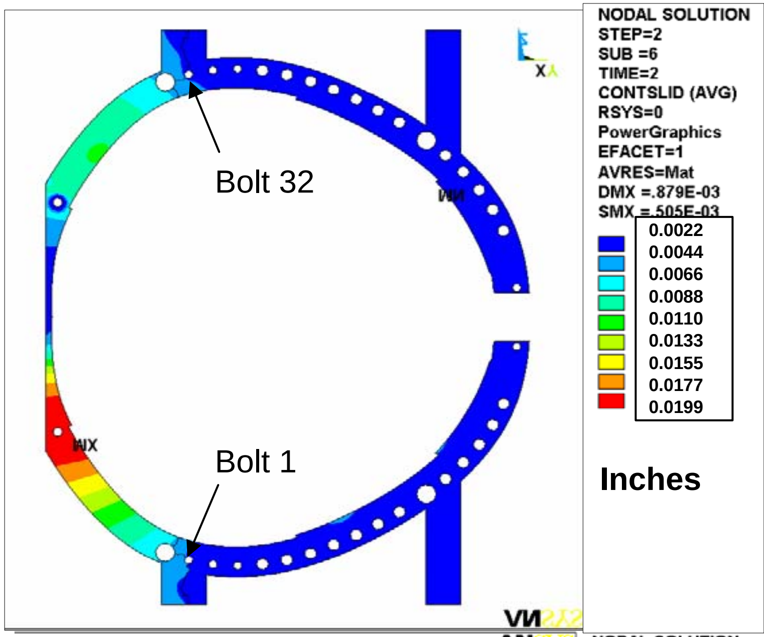


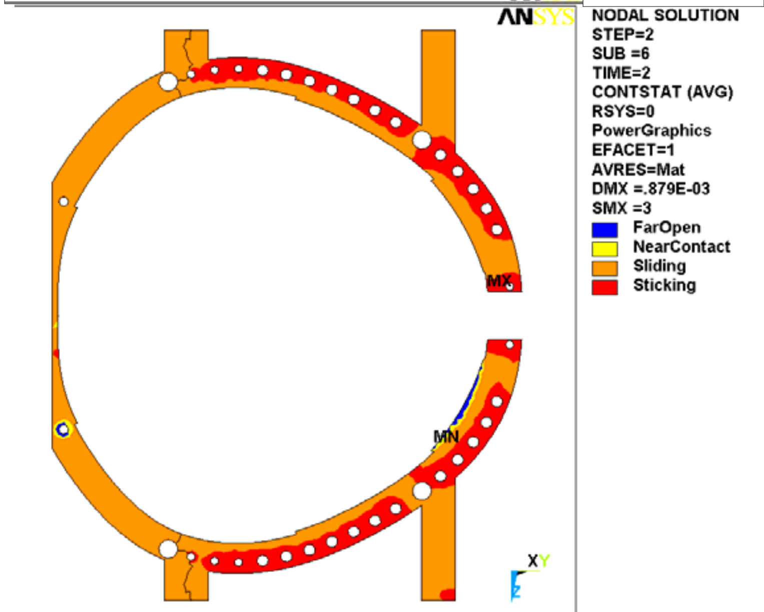
Contact Sliding regions



Friction = 0.04 on Inner-leg region







No Inboard Bolt Friction

Frictionless In board leg

Peak Shear is 4.8 Kips

Sliding is 19 mils

Friction = 0.4 everywhere on flange

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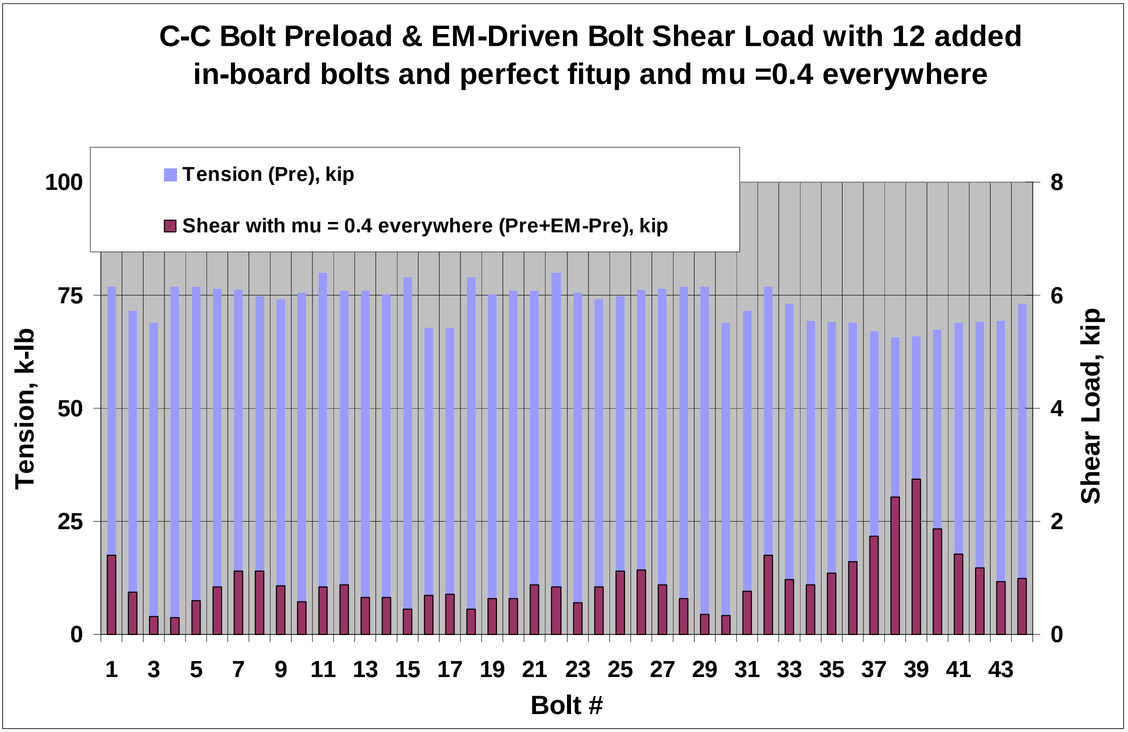
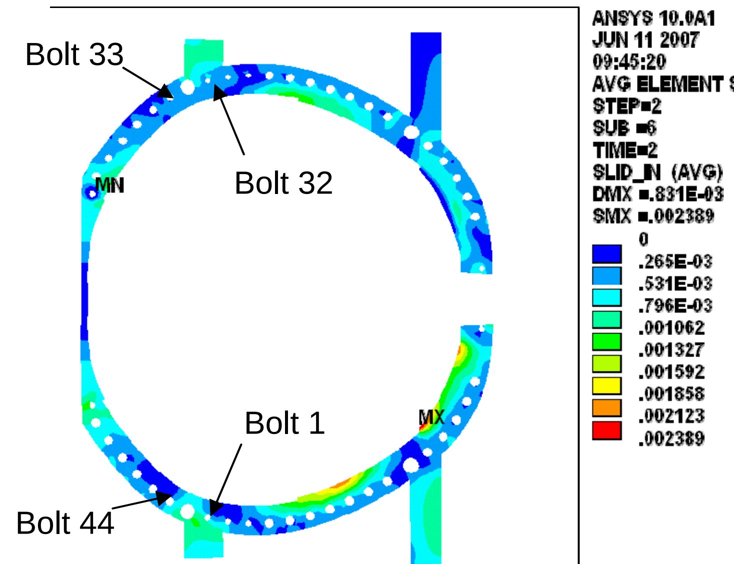
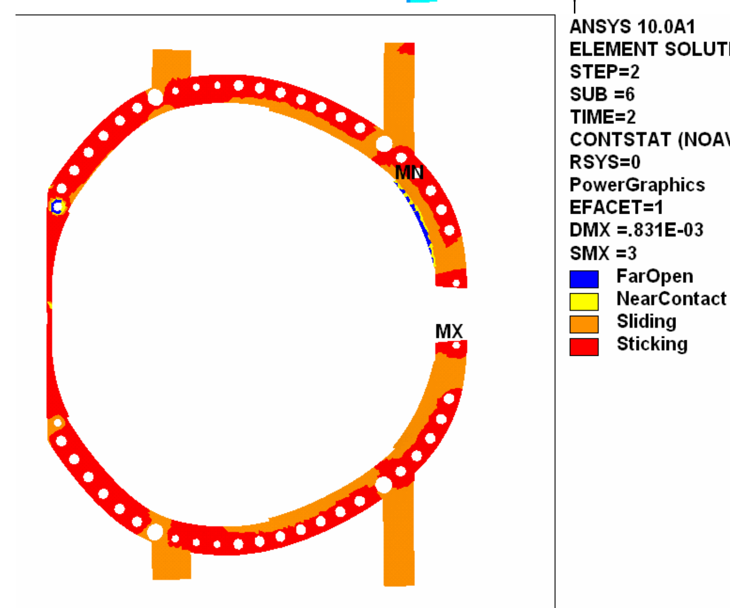




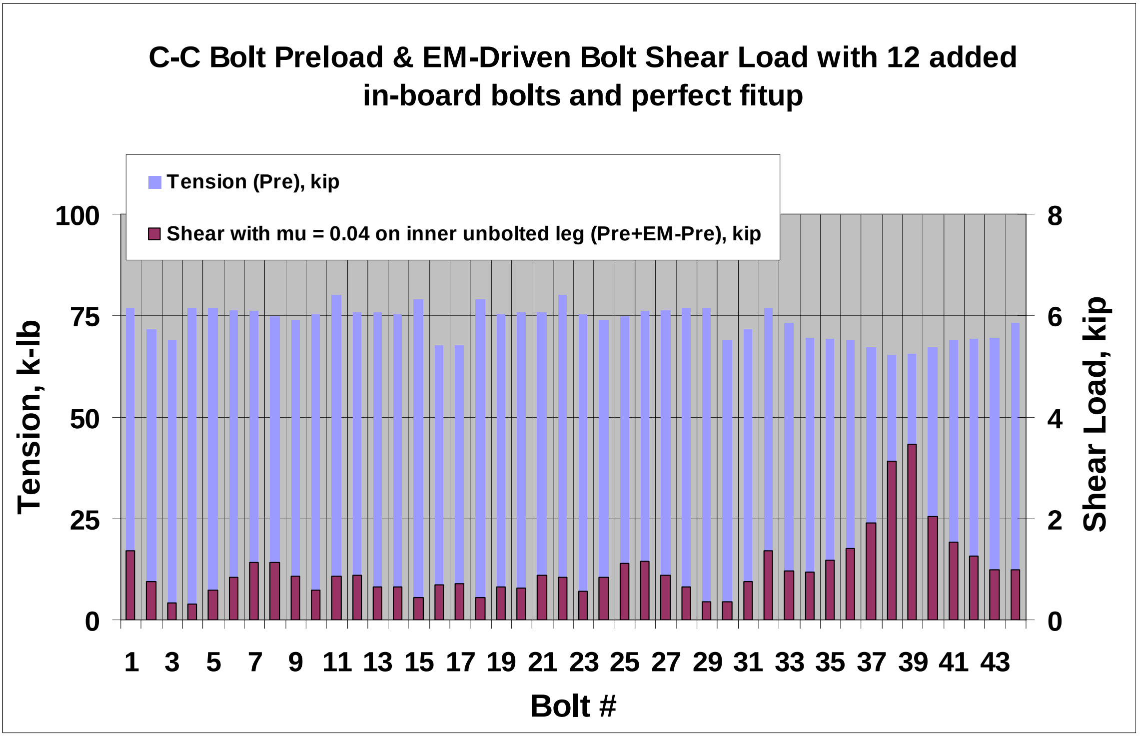


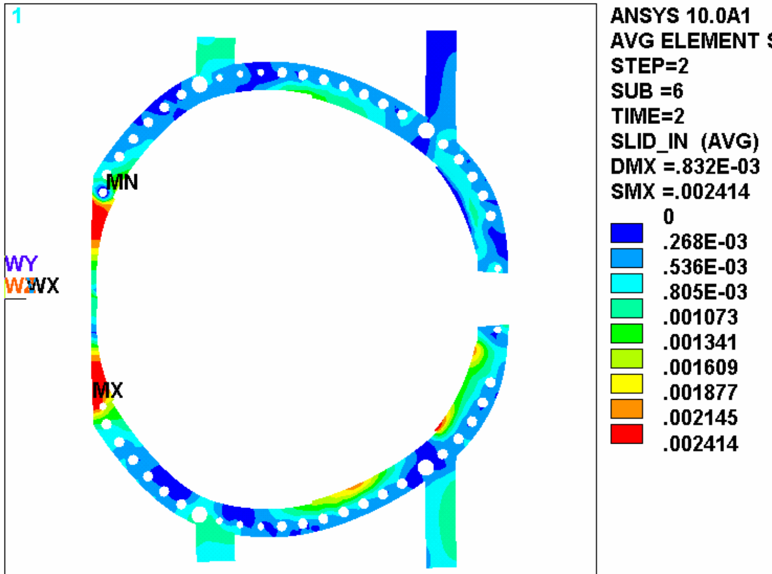
ADDED 12 Inboard Bolts

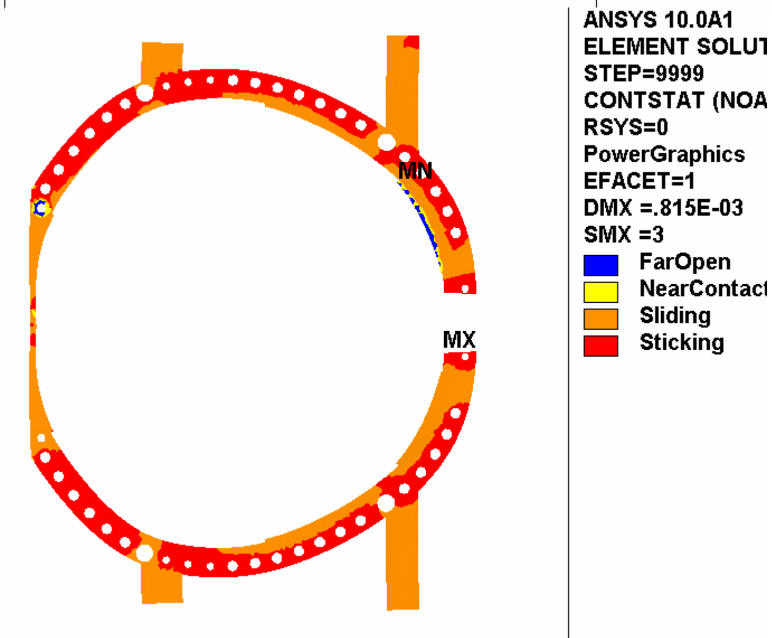
Inner most bolts see 2.7 Kips

Sliding is less than 1.3 mils

Friction = 0.04 on Inner-leg region, mu = 0.4 everywhere else







ADDED 12 Inboard Bolts

Inner most bolts see 3.4 Kips

Sliding is less than 2.4 mils

Max sliding and bolt shear table

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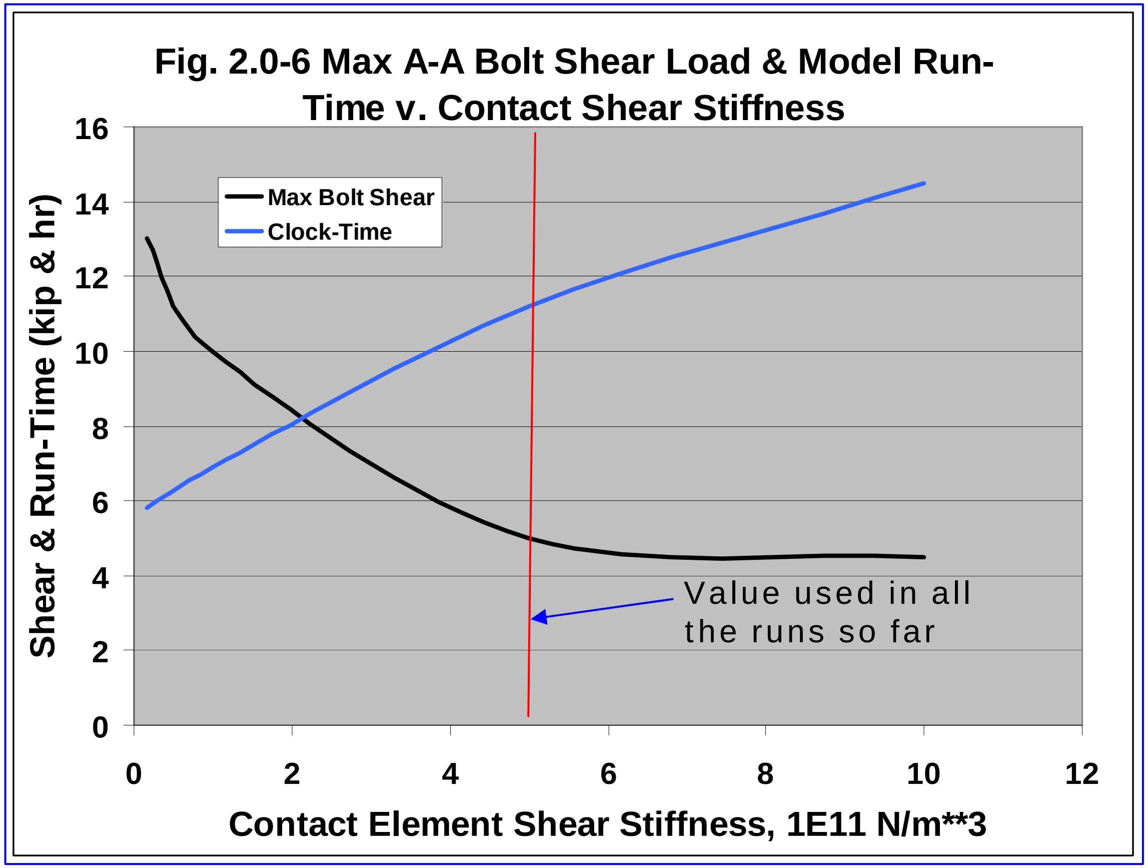
Bolt Size (in)	Inboard Friction	# of inboard bolts	Max sliding distance (in)	Max Shear Force (kips)
1.375	0.4	0	0.0065	2.8
1.375	0.4	6	0.0047	2.4
1.375	0.4	12	0.0011	2.7
1.375	0.04	0	0.0199	4.9
1.375	0.04	6	0.0143	4.5
1.375	0.04	12	0.0024	3.5
1.5	0.04	6	0.014	4.7
1.5	0.04	12	0.0024	3.8
1.375	Imperfect fit-up (5 mil gap)	0	0.0193	3.3

- Number of bolts is the total number added: 12 bolts means 6 bolts added above and below the mid-plane.
- Little difference in sliding or shear force noted between the 1.375” and the 1.5” bolts: Contact stiffness explains shear force (next slides)

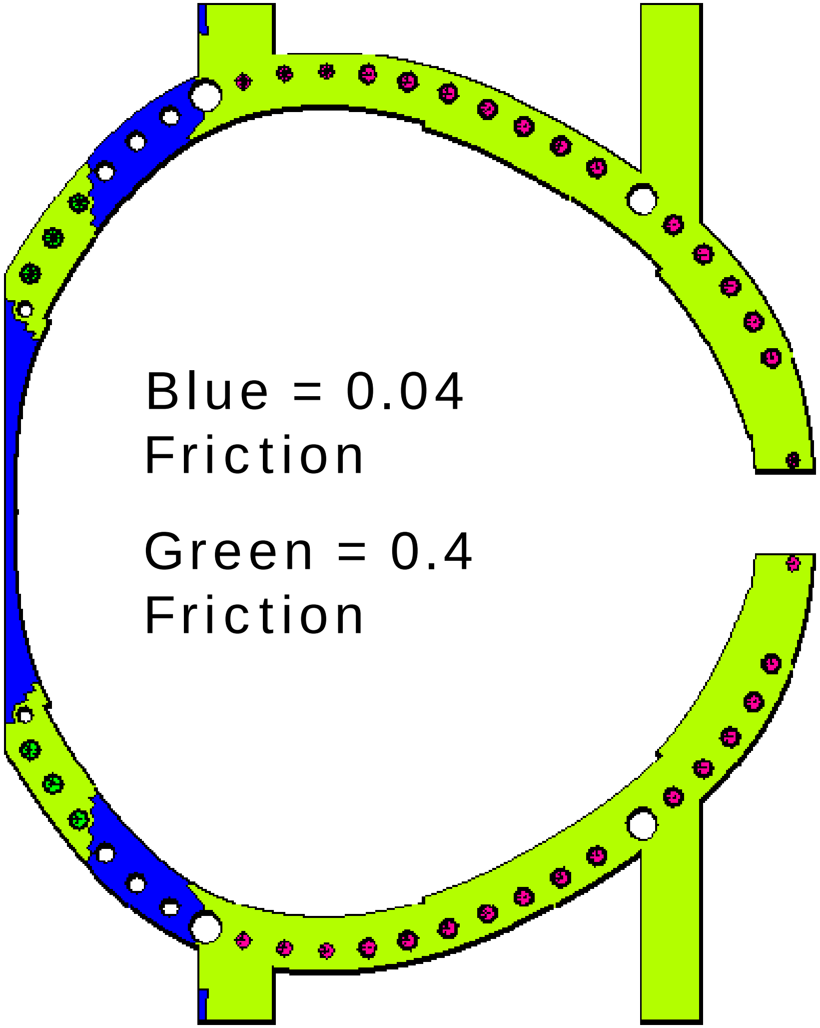
Problem discovered in May 2007

- "Following the presentation of numerous global model results which showed high shear loads in some of the bolts, a detailed review of the contact element characteristics uncovered a defect in the model.
- The default contact element shear stiffness (~0.17E11 N/m3) was found to be too soft, and flange faces slipped when they should have been stuck.
- Over-riding the default shear stiffness value with incremental increases produced lower bolt shear loads and longer computer run-times for the representative A-A interface.
- A shear stiffness of 5E11 N/m3 seems to provide a reasonable compromise in accuracy and run-time.



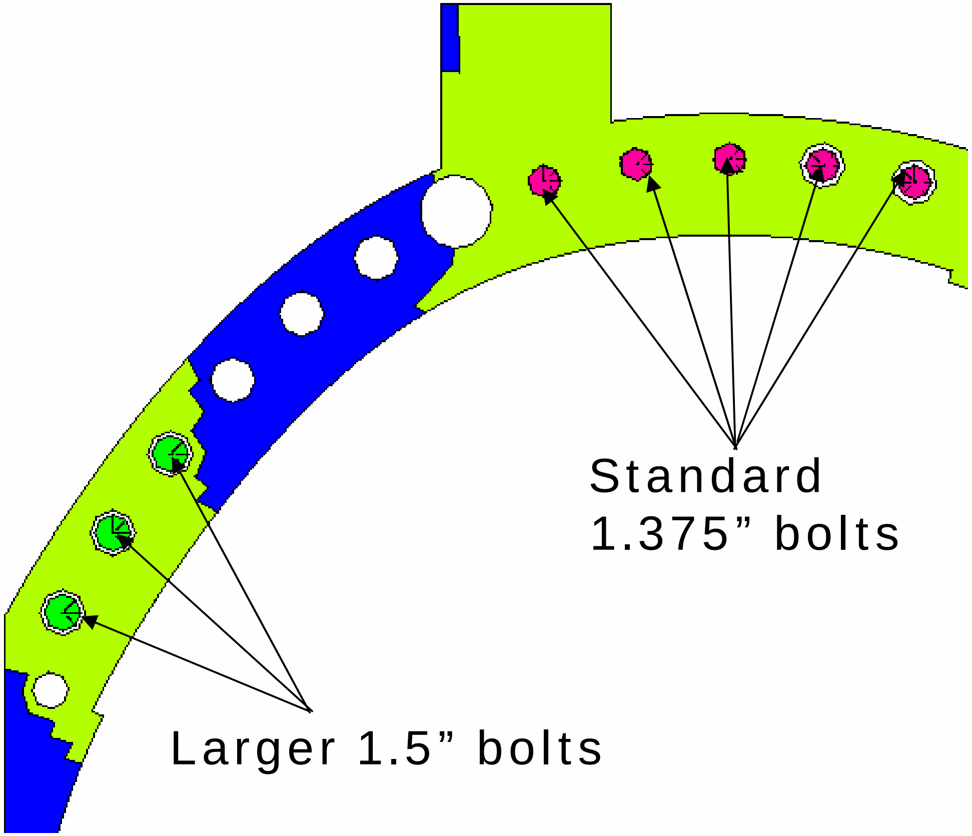
Case Study:

Three 1.5” Innermost Bolts Added

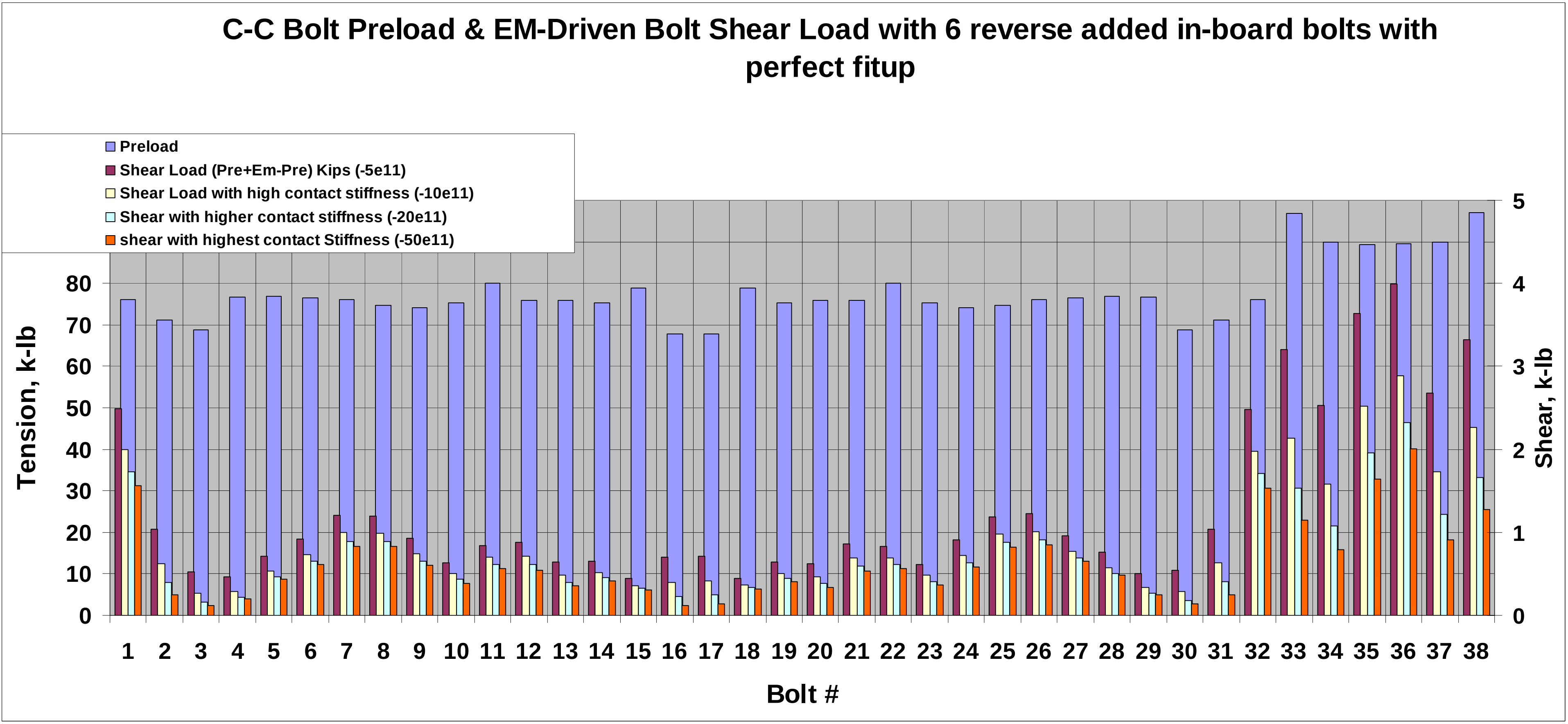


Blue = 0.04 Friction

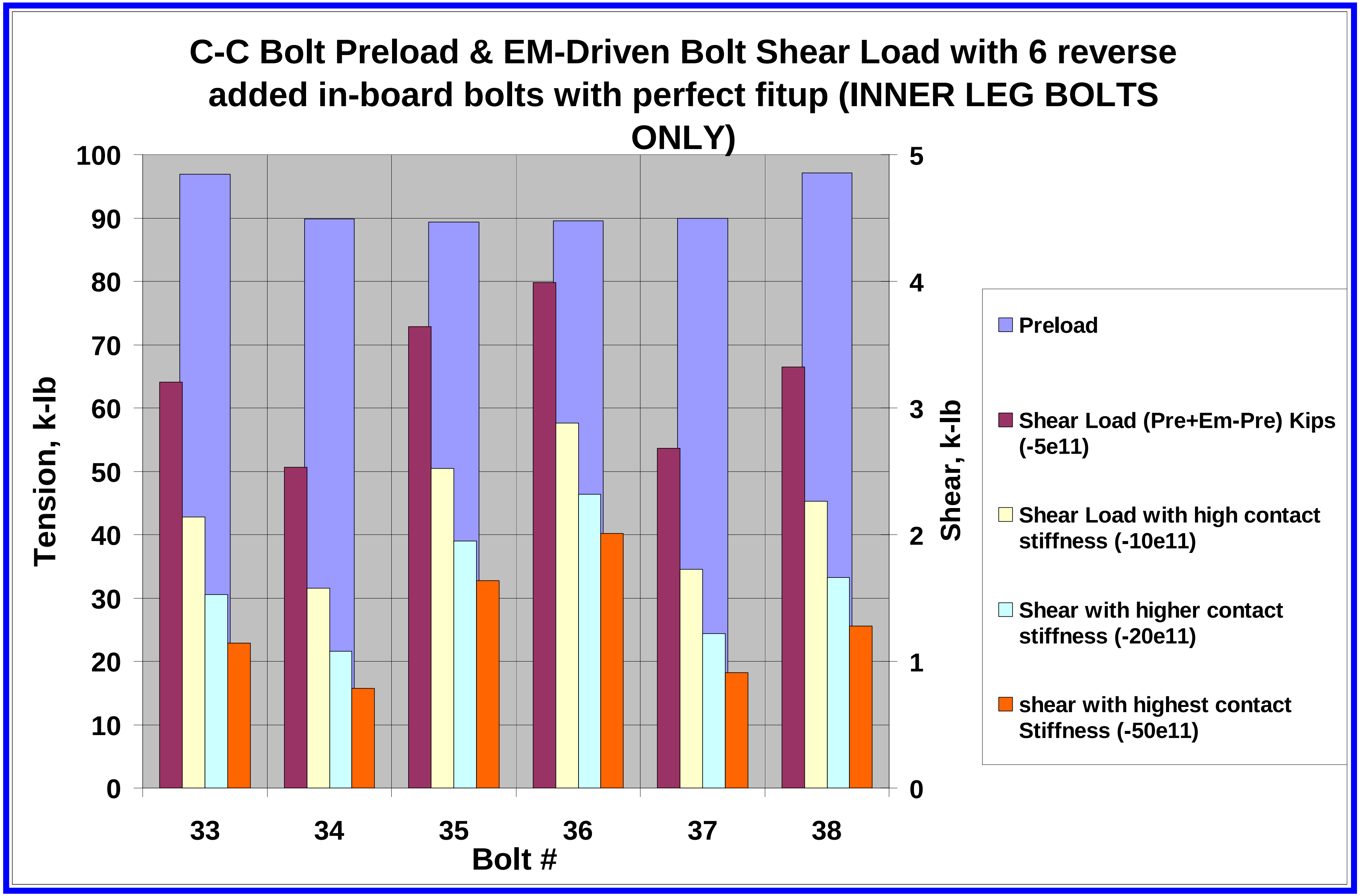
Green = 0.4 Friction



Shear Force on Inner Leg of CC



Inner Leg Bolts Only



Contact Slip Plots

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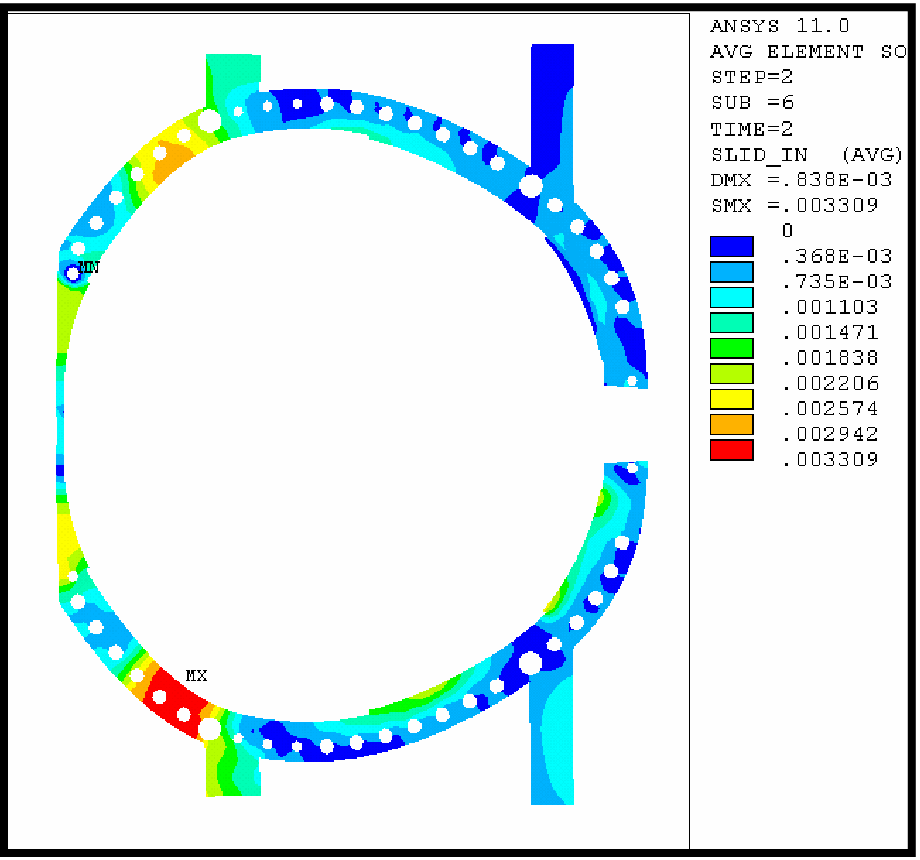
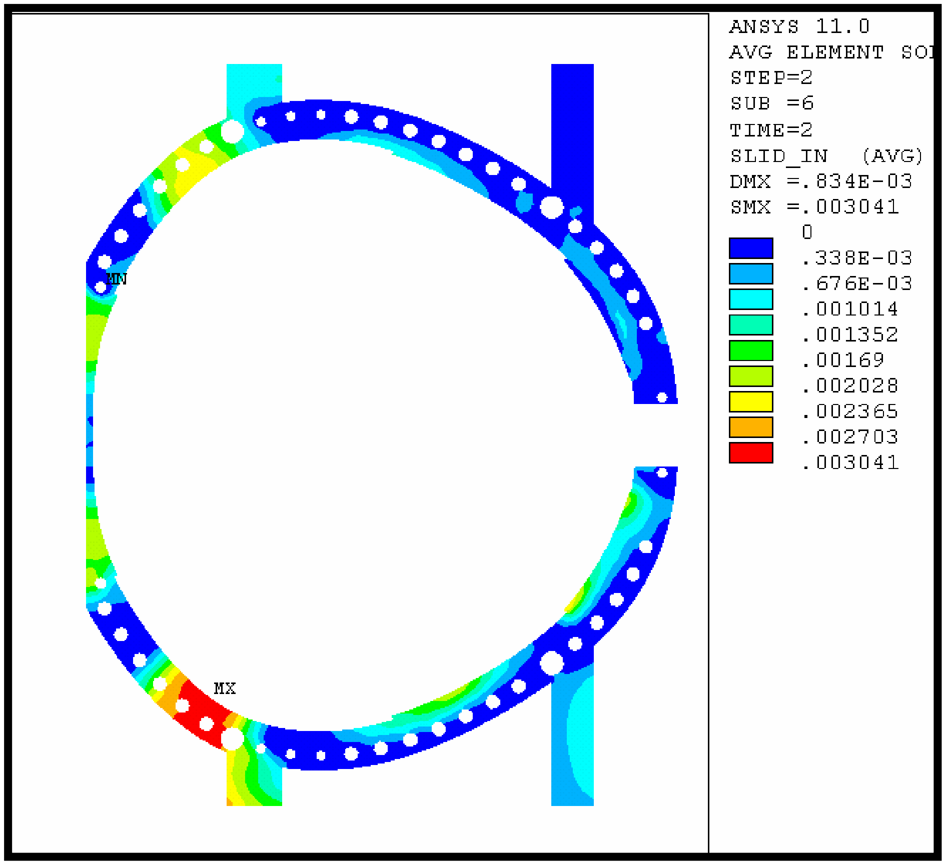


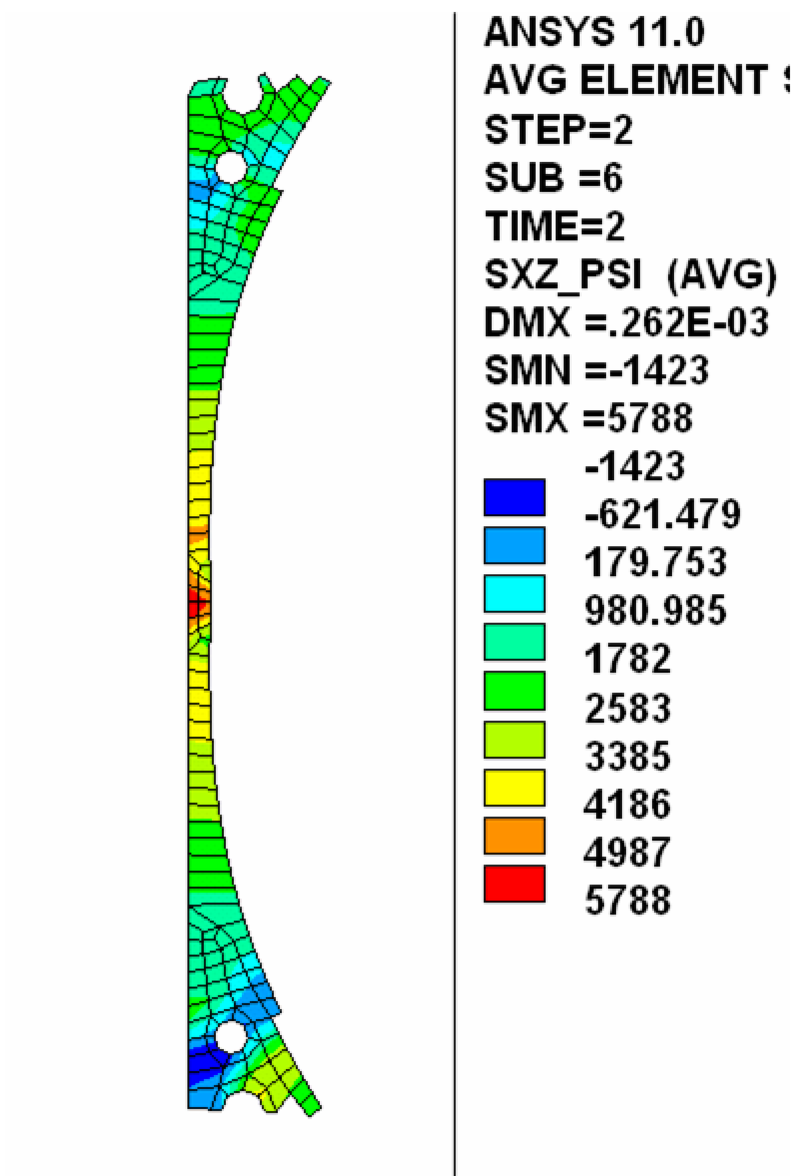
Stiffness = -5e11 N/m^3



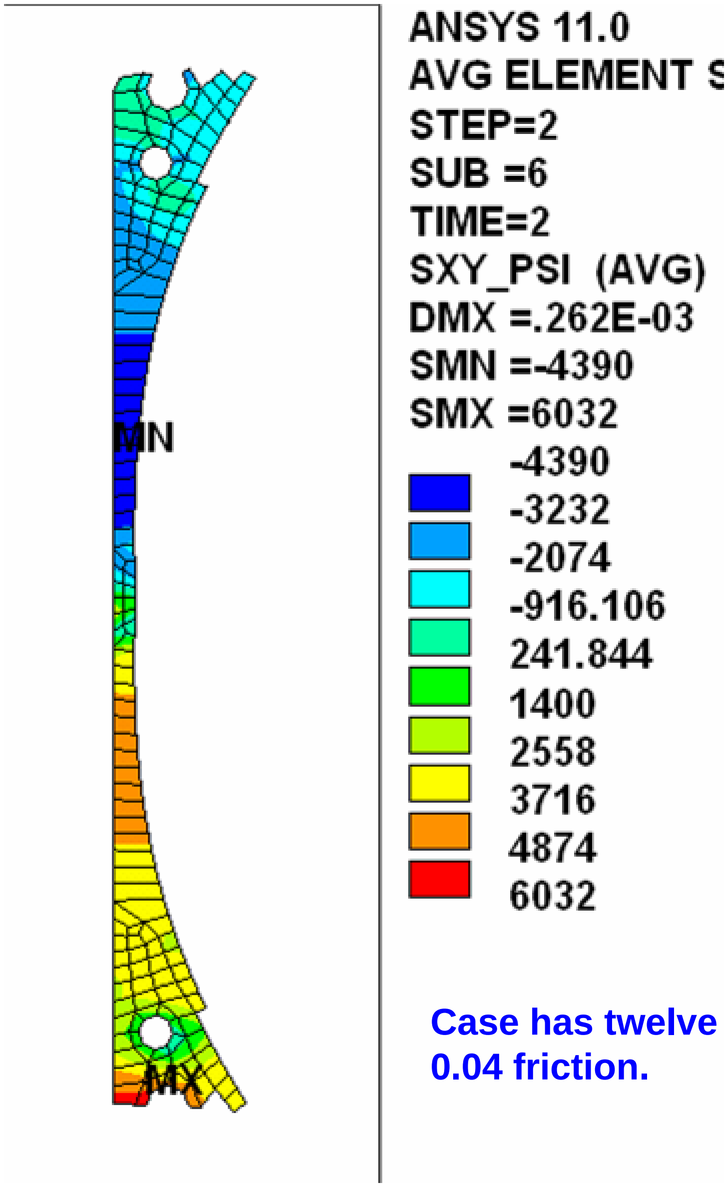
Stiffness = -50e11 N/m^3

The contact stiffness overestimates the shear force but has little effect on sliding.

Unbolted Inner leg Shims (shear)



Horizontal Shear



Case has twelve 1.5” bolts with 0.04 friction.

Vertical Shear

Analysis Summary

- Adding 12 bolts to the CC flange essentially eliminates inner leg sliding (< 2.5 mils for all friction cases.
- All 12 bolts are stuck and see limited shear from flange/flange stiffness/deflection.
- Going to 1.5” bolts has limited effect.
- The unbolted region will see limited shear (less than 6 ksi) if 12 bolts are used.
- A more detailed sub-model of unbolted inner leg shims may be needed to determine weld strength to prevent shims from dislodging. *Positioning holes can also be used to hold shims

Plan to complete final design

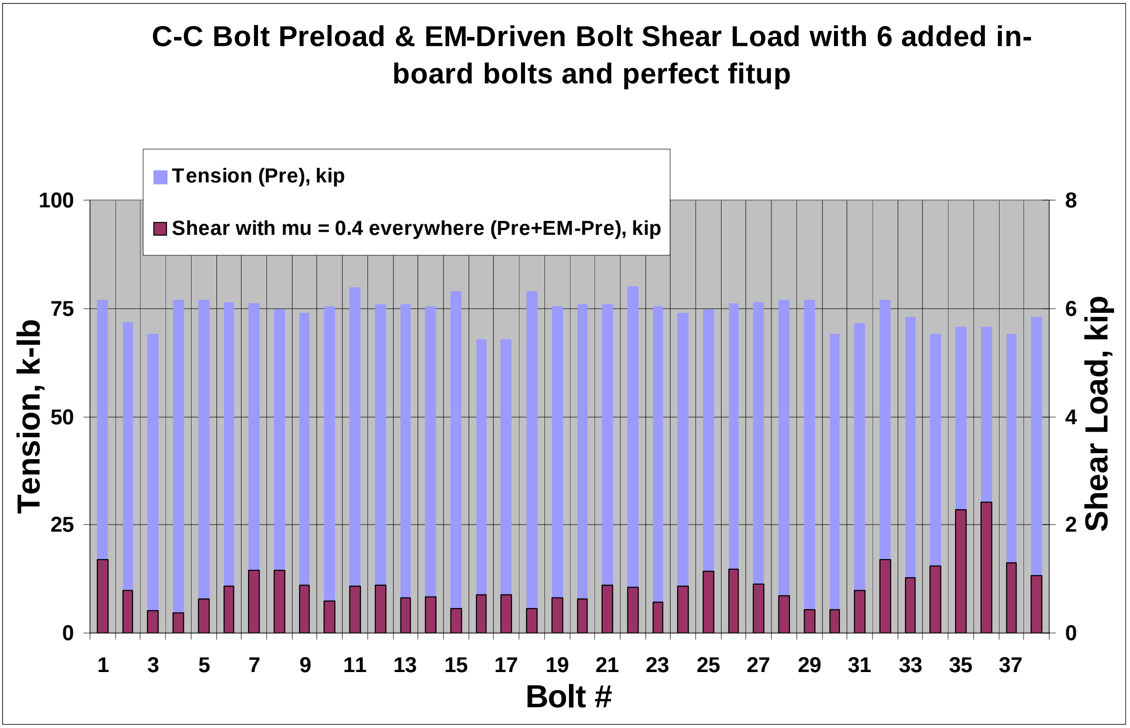
Task	Description	Finish
IH1-0000	PDR C-C Inboard Interface	7-Aug
1421-3143	Issue dwg w/ additional holes (SE141-148)	17-Aug
1421-3140	Issue dwg for C-C shims (SE140-055)	
1421-3145	Mockup and access studies	8-Oct
---	Develop inboard bolt installation concepts	30-Oct
---	Fab / procure hardware for inb bolt installation	28-Dec
---	Conduct field trial on actual CC or BCC fit-up	30-Jan
1421-3144	FDR C-C Inboard Interface	15-Feb

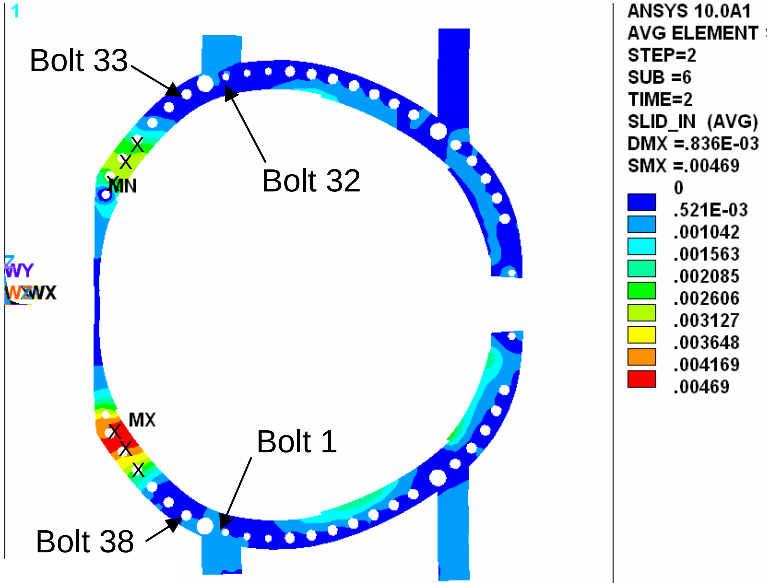
Conclusion

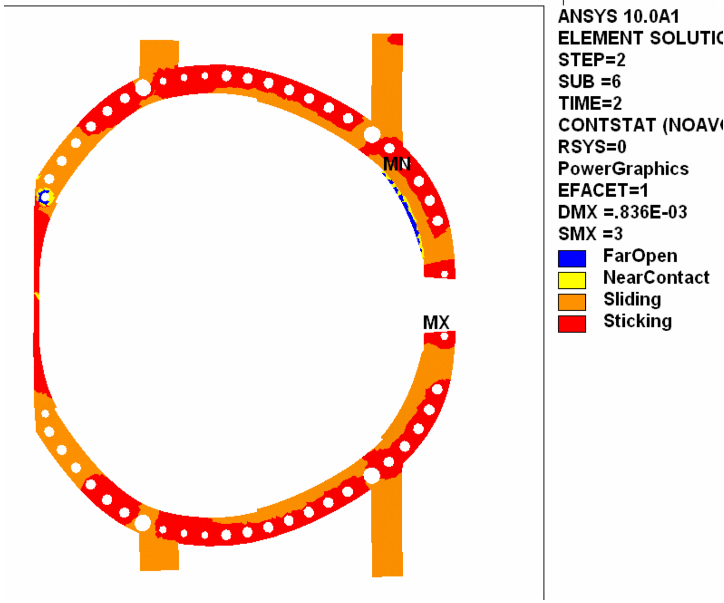
- Are the requirements defined? What is the proposed design?
  Additional holes, shim layout complete
- What is the status of mockup and access studies?
  Bolt installation is feasible, development + testing planned
- Is the analysis consistent with proposed design?
  Twelve additional bolts eliminates need for sliding shims
- Have prior design review chits been addressed?
  Bolt asm, welded shims FDRs addressed relevant issues
- Have all technical, cost, schedule, and safety risks been addressed?
  Access tooling development planned

Backup Slides

Friction = 0.4 everywhere on flange through alumina shims.







ADDED 6 Inboard Bolts

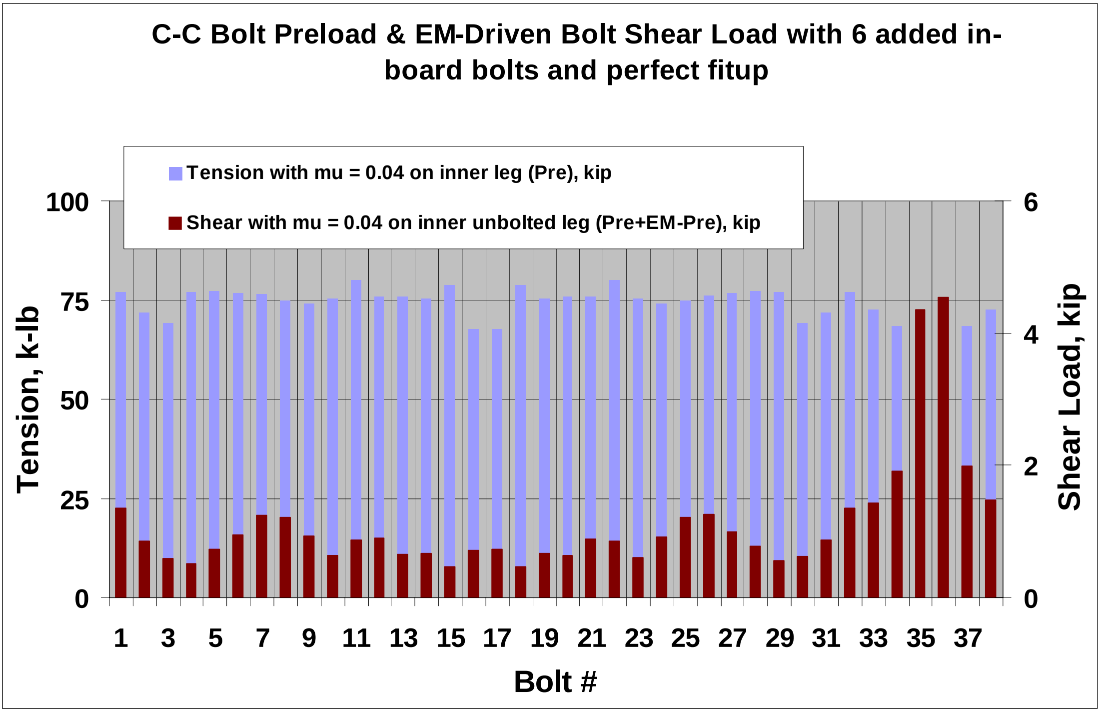
Innermost 6 bolts are shown but not used in the calculation (shown as x's in the sliding picture)

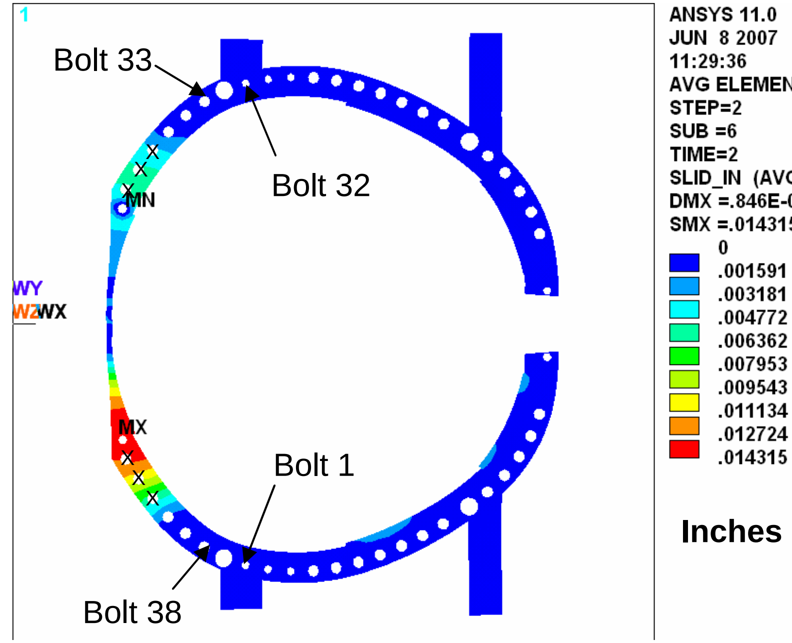
Inner most bolts see 2.4 Kips

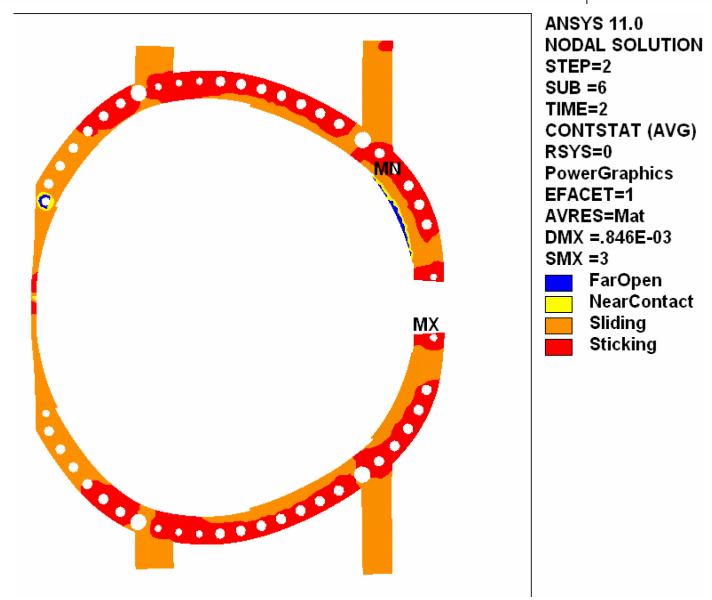
Sliding is 4.7 mils

Friction = 0.04 on Inner-leg region, mu = 0.4 everywhere else

NCSX NATIONAL COMPACT STELLARATOR EXPERIMENT







ADDED 6 Inboard Bolts

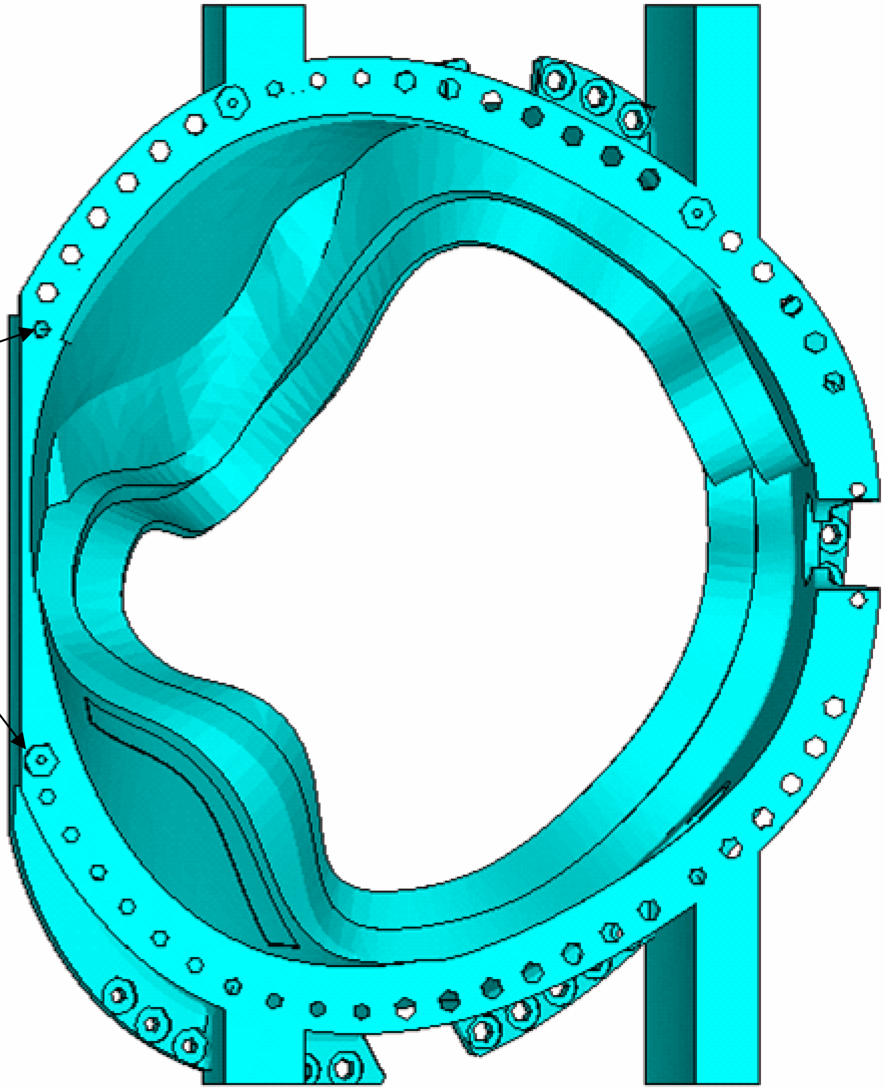
Frictionless In board leg

Peak Shear is 4.8 Kips

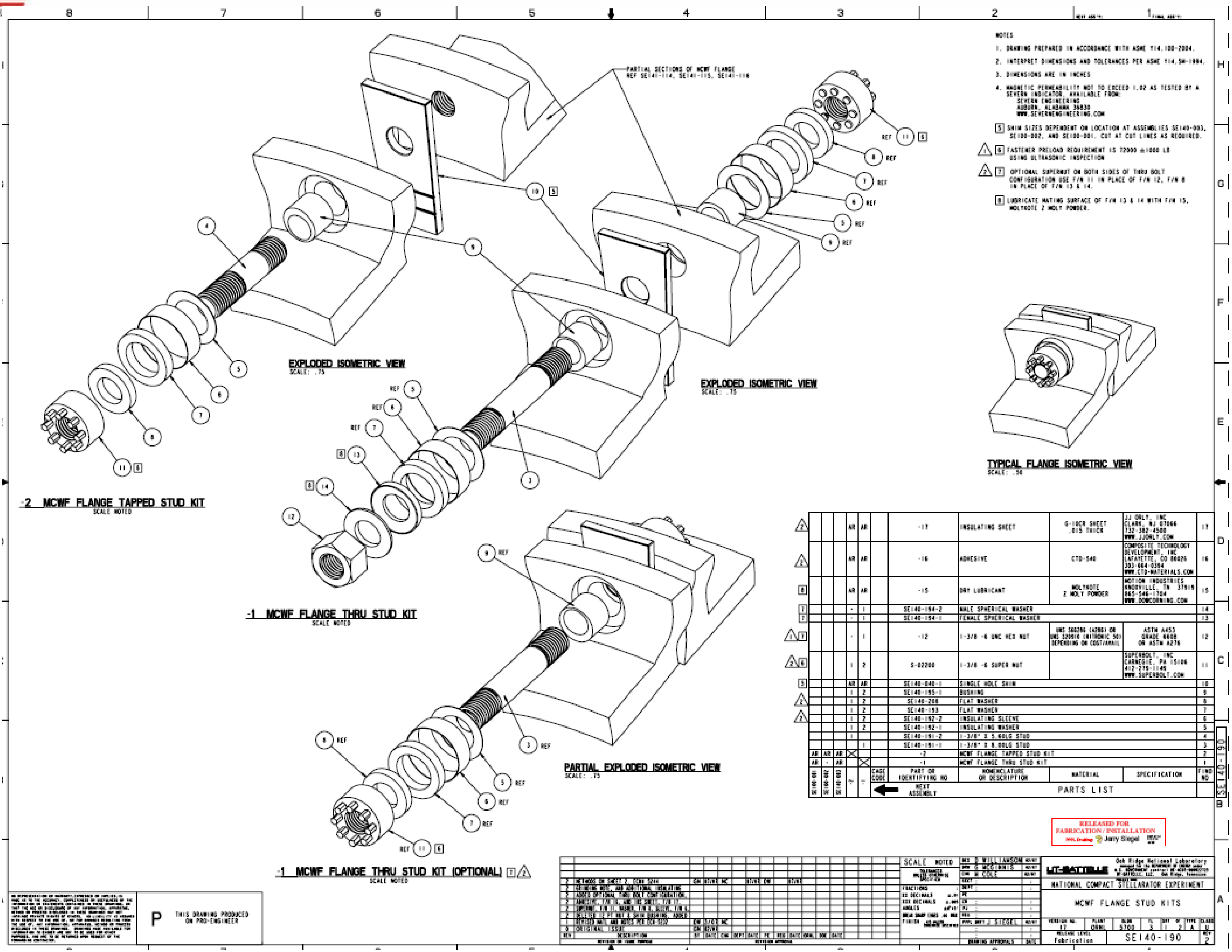
Sliding is 14 mils

Positioning hole on CC interface

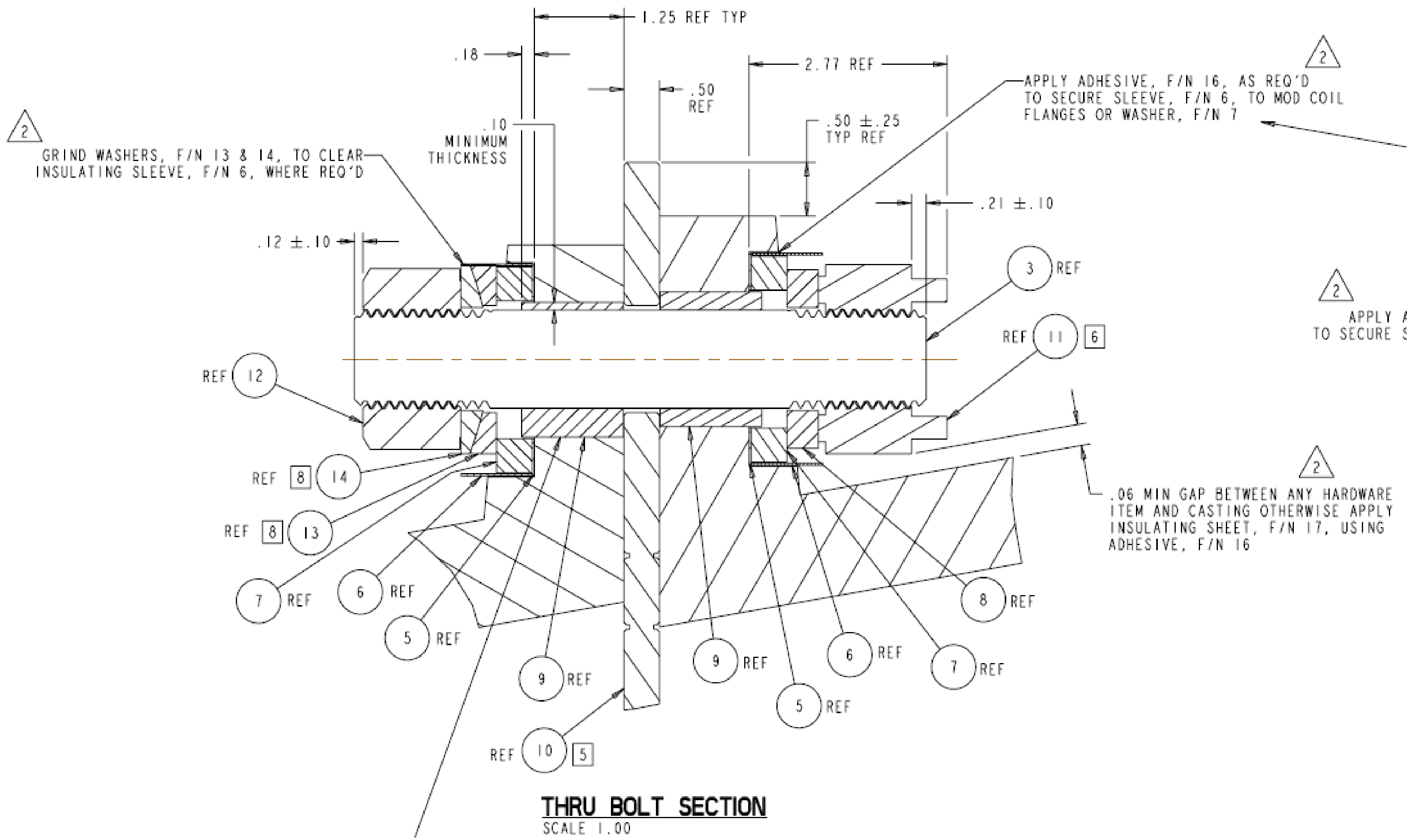
These two positioning holes are an ideal place to secure inner shims more tightly if needed.



Bolted Joint Asm (SE140-190-R2)



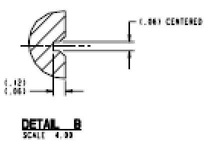
Bolted Joint Asm (SE140-190-R2)

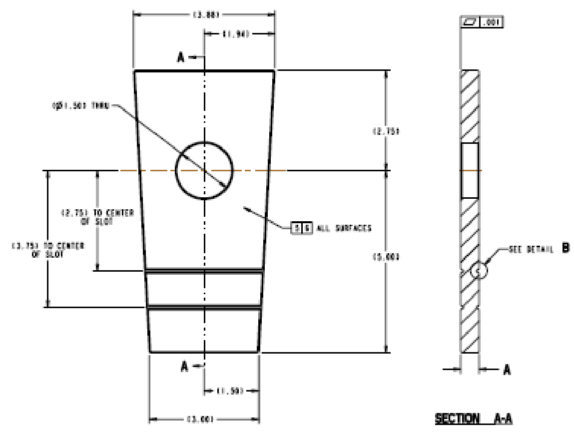


THRU BOLT SECTION
SCALE 1.00

Shim (SE140-040-R0)

NCSX National Compact Stellarator Experiment





-1 SHINGLE HOLE SHIM
SCALE 1.00

NOTE: DIMENSIONS SHOWN ON THIS SHEET APPLY AFTER COATING

SEE SHEET 2 FOR NON-COATED PART

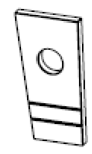
NOTES

1. DRAWING PREPARED IN ACCORDANCE WITH ASME Y14.100-2004.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES
4. MAGNETIC PERMEABILITY NOT TO EXCEED 1.02 AS TESTED BY A SEVERN INDICATOR. AVAILABLE FROM:
   SEVERN ENGINEERING
   AUBURN, ALABAMA 36830
   WWW.SEVERNENGINEERING.COM

   IF PERMEABILITY SPEC IS NOT ACHIEVED THEN SOLUTION ANNEAL PART PRIOR TO COATING.
5. ALUMINA COATING PER SPECIFICATION NCSX-CSPEC-142-06-00.
6. SURFACE FINISH AFTER COATING 150-500.
   SURFACE FINISH ON NON-COATED PART 125 OR LESS UNLESS OTHERWISE SPECIFIED BY COATING SUPPLIER.

TOTAL 214

QTY REQ'D	DIM A FINISHED SIZE ALUMINA COATED THICKNESS PER SIDE .025 +.003 / -.002	MIN (FINISHED SIZE)	MAX (FINISHED SIZE)	THICKNESS OF SS ± .001	PART NO
1	.540	.535	.547	.490	-36
1	.538	.533	.545	.488	-35
1	.536	.531	.543	.486	-34
1	.534	.529	.541	.484	-33
2	.532	.527	.539	.482	-32
2	.530	.525	.537	.480	-31
3	.528	.523	.535	.478	-30
4	.526	.521	.533	.476	-29
5	.524	.519	.531	.474	-28
6	.522	.517	.529	.472	-27
7	.520	.515	.527	.470	-26
8	.518	.513	.525	.468	-25
9	.516	.511	.523	.466	-24
10	.514	.509	.521	.464	-23
10	.512	.507	.519	.462	-22
11	.510	.505	.517	.460	-21
12	.508	.503	.515	.458	-20
12	.506	.501	.513	.456	-19
12	.504	.499	.511	.454	-18
12	.502	.497	.509	.452	-17
11	.500	.495	.507	.450	-16
11	.498	.493	.505	.448	-15
10	.496	.491	.503	.446	-14
9	.494	.489	.501	.444	-13
8	.492	.487	.499	.442	-12
7	.490	.485	.497	.440	-11
6	.488	.483	.495	.438	-10
5	.486	.481	.493	.436	-9
4	.484	.479	.491	.434	-8
4	.482	.477	.489	.432	-7
3	.480	.475	.487	.430	-6
2	.478	.473	.485	.428	-5
2	.476	.471	.483	.426	-4
1	.474	.469	.481	.424	-3
1	.472	.467	.479	.422	-2
1	.470	.465	.477	.420	-1



ISOMETRIC VIEW
SCALE .50

PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
SEE CHART	SINGLE HOLE SHIM	316 SST 4 PLASMA ALUMINA COATED 5	ASTM A240	1

PARTS LIST

RELEASED FOR FABRICATION / INSTALLATION
Jerry Siegel

P THIS DRAWING PRODUCED ON PRO-ENGINEER

0 ORIGINAL ISSUE

NATIONAL COMPACT STELLARATOR EXPERIMENT

SINGLE HOLE SHIM PLATE

SE140-040