Modular Coil Interface Hardware
C-C Joint FDR

Presented by
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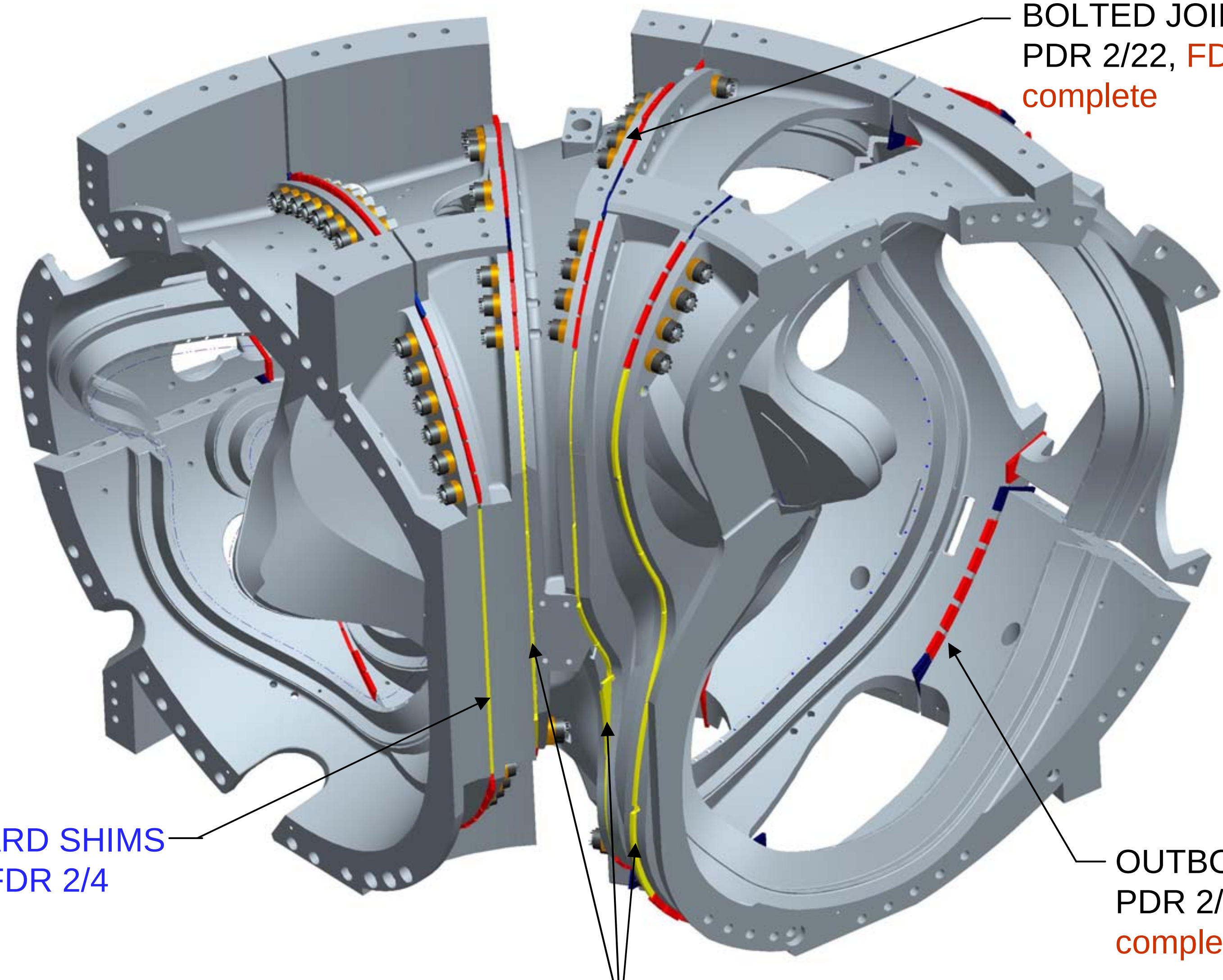
February 4, 2008

Review Charge

- Are the requirements defined? What is the proposed design?
- What are the results of 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
CC INBOARD SHIMS
PDR 8/7, FDR 2/4
OUTBOARD SHIMS
PDR 2/22, FDR 6/29
complete
AA/AB/BC INBOARD SHIMS
PDR 10/18, FDR 11/27 complete

The design requirements for the C to C Joint are derived from the Modular Coil Asm Specification (NCSX-CSPEC-14-05-01). The design of the C to C Joints are defined in the drawings presented at this design review. The product specification covering the assembly of the C to C Joint is the station 6 product specification which has not yet been drafted.

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

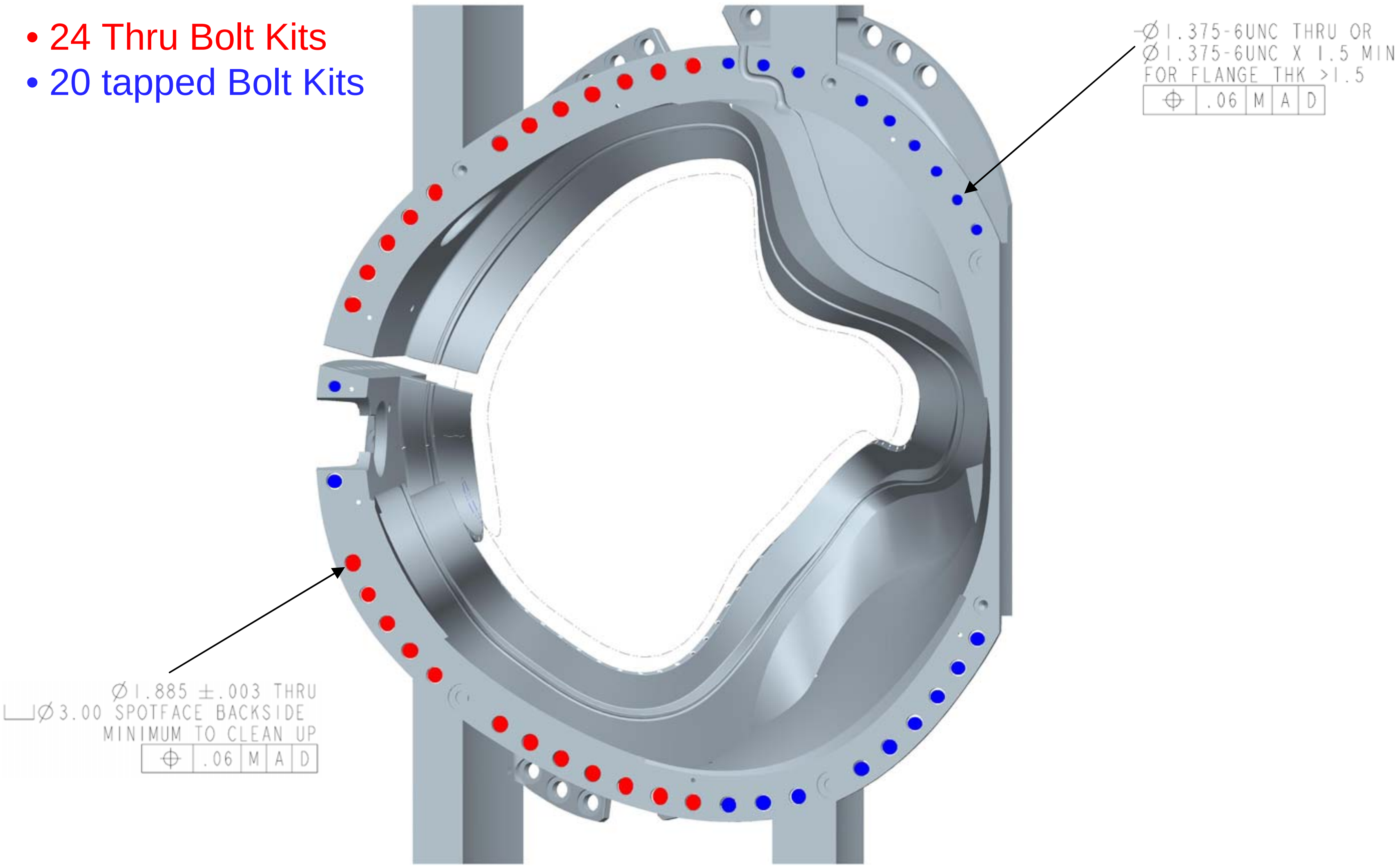
- Carry loads up to 15-ksi compression, 4-kip/in shear
- Maintain a “no slip condition” under the bolts (friction joint)

Assembly

- Position the coils accurately
- Minimize gaps

C-C Holes and Bolts

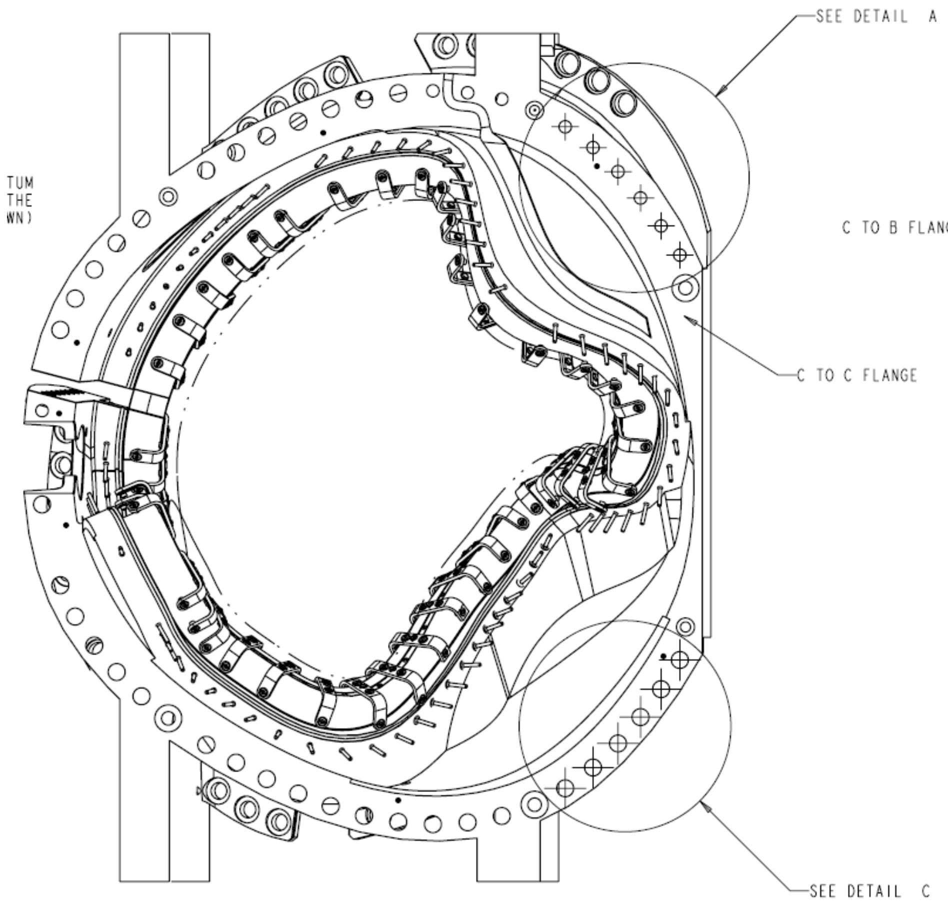
- 24 Thru Bolt Kits
- 20 tapped Bolt Kits



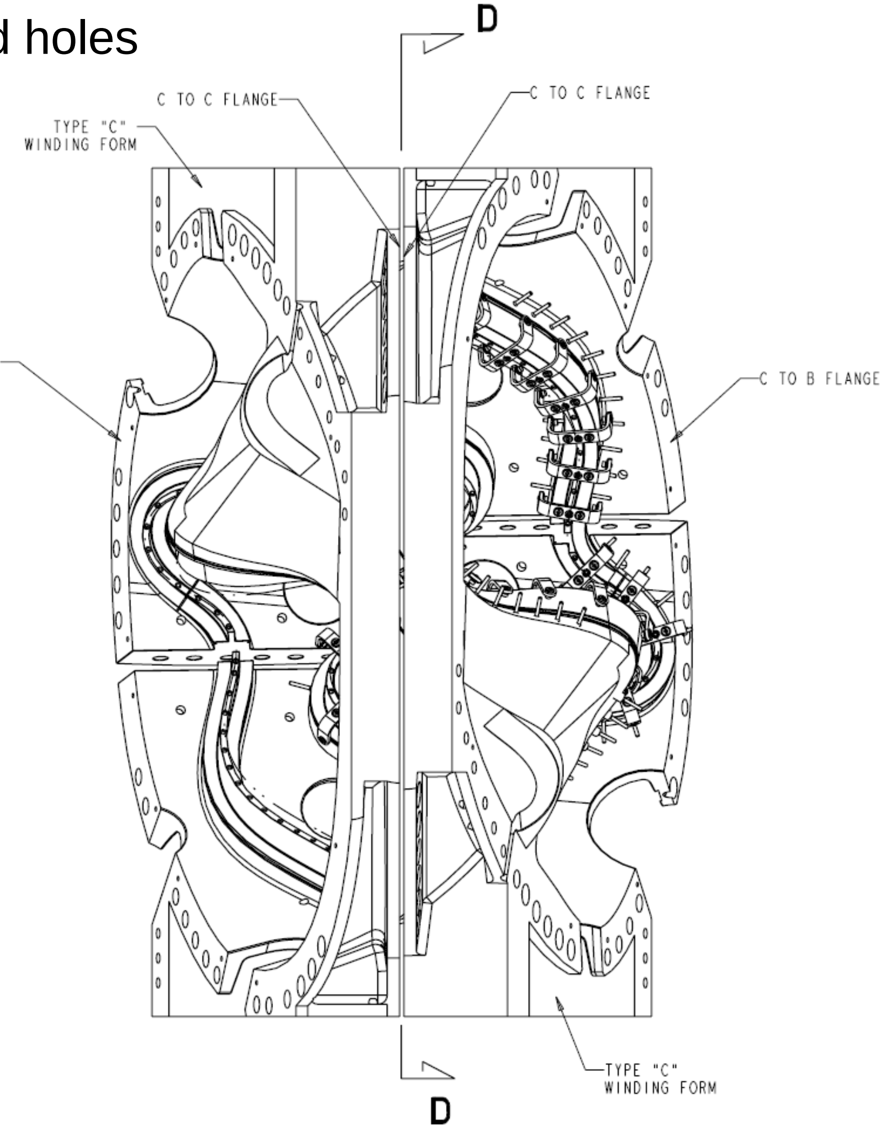
Winding Form Modification

NCSX
National Compact Stellarator Experiment

- SE141-148 defines 12 additional inboard holes



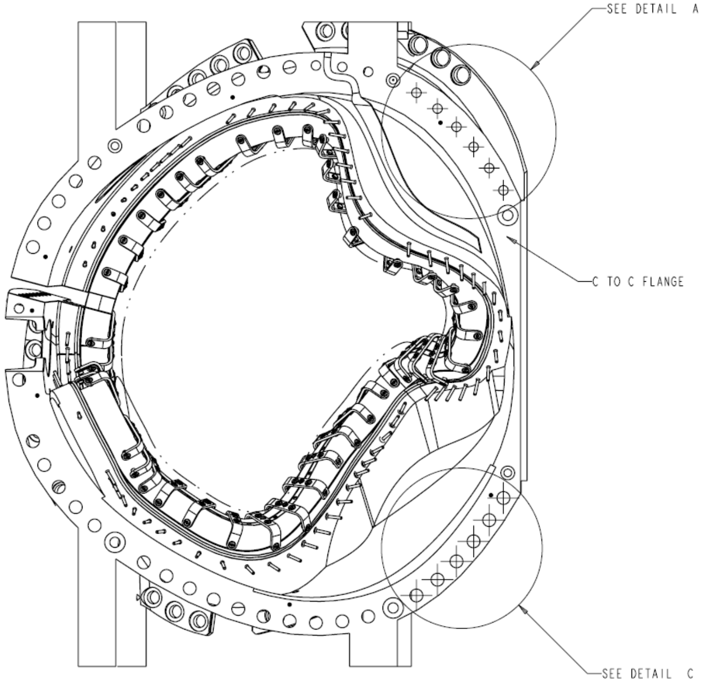
VIEW D - D
TYPE C WINDING FORM VIEW OF C-C FLANGE, DATUM E
MAY BE PART ONLY OR PARTIALLY ASSEMBLIED
SCALE 0.12



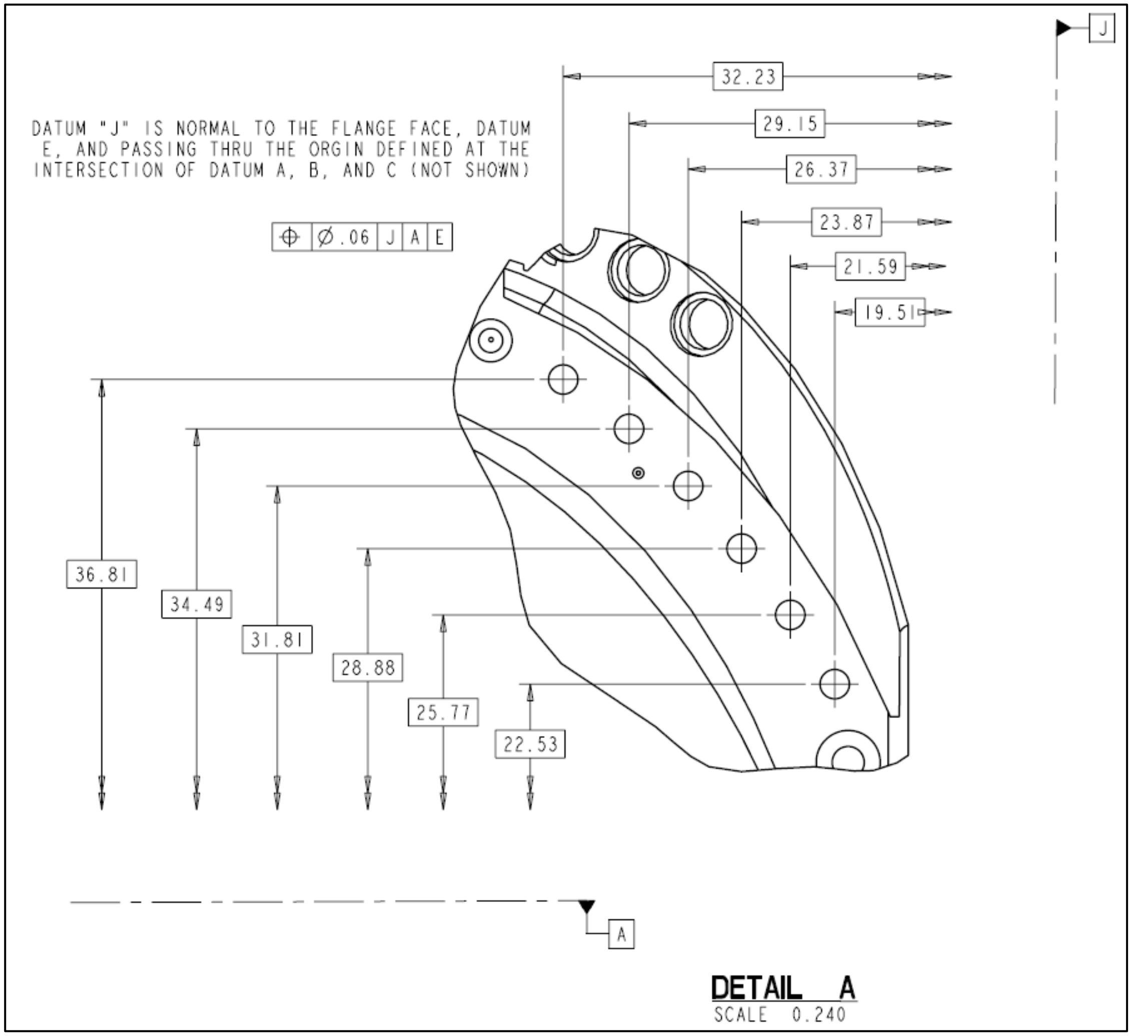
Hole specification:

Ø1.375-6UNC THRU OR
Ø1.375-6UNC X 1.5 MIN
FOR FLANGE THK >1.5

Ø1.885 ±.003 THRU
Ø3.00 SPOTFACE BACKSIDE
MINIMUM TO CLEAN UP

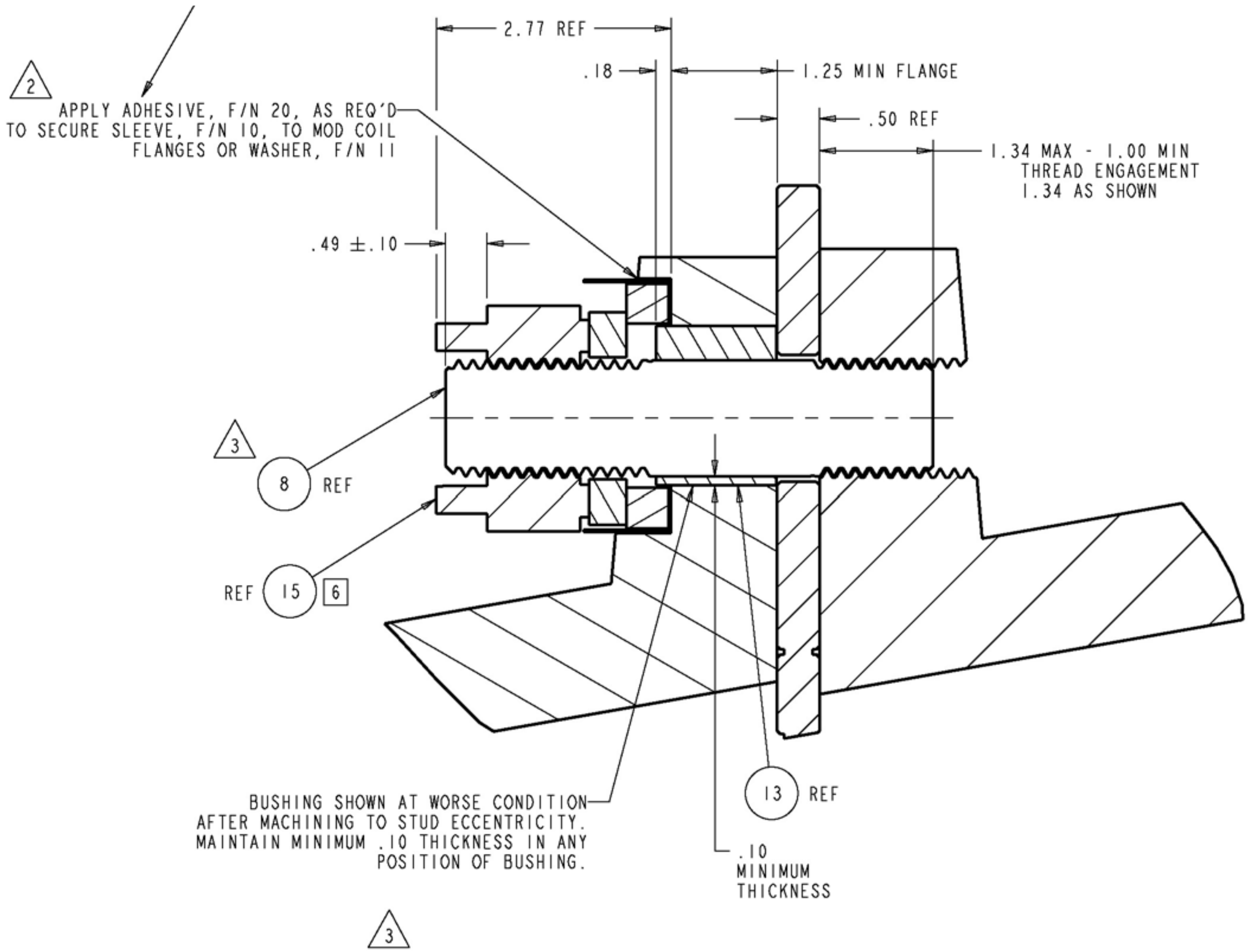


VIEW D - D
TYPE C WINDING FORM VIEW OF C-C FLANGE, DATUM E
MAY BE PART ONLY OR PARTIALLY ASSEMBLIED
SCALE 0.12



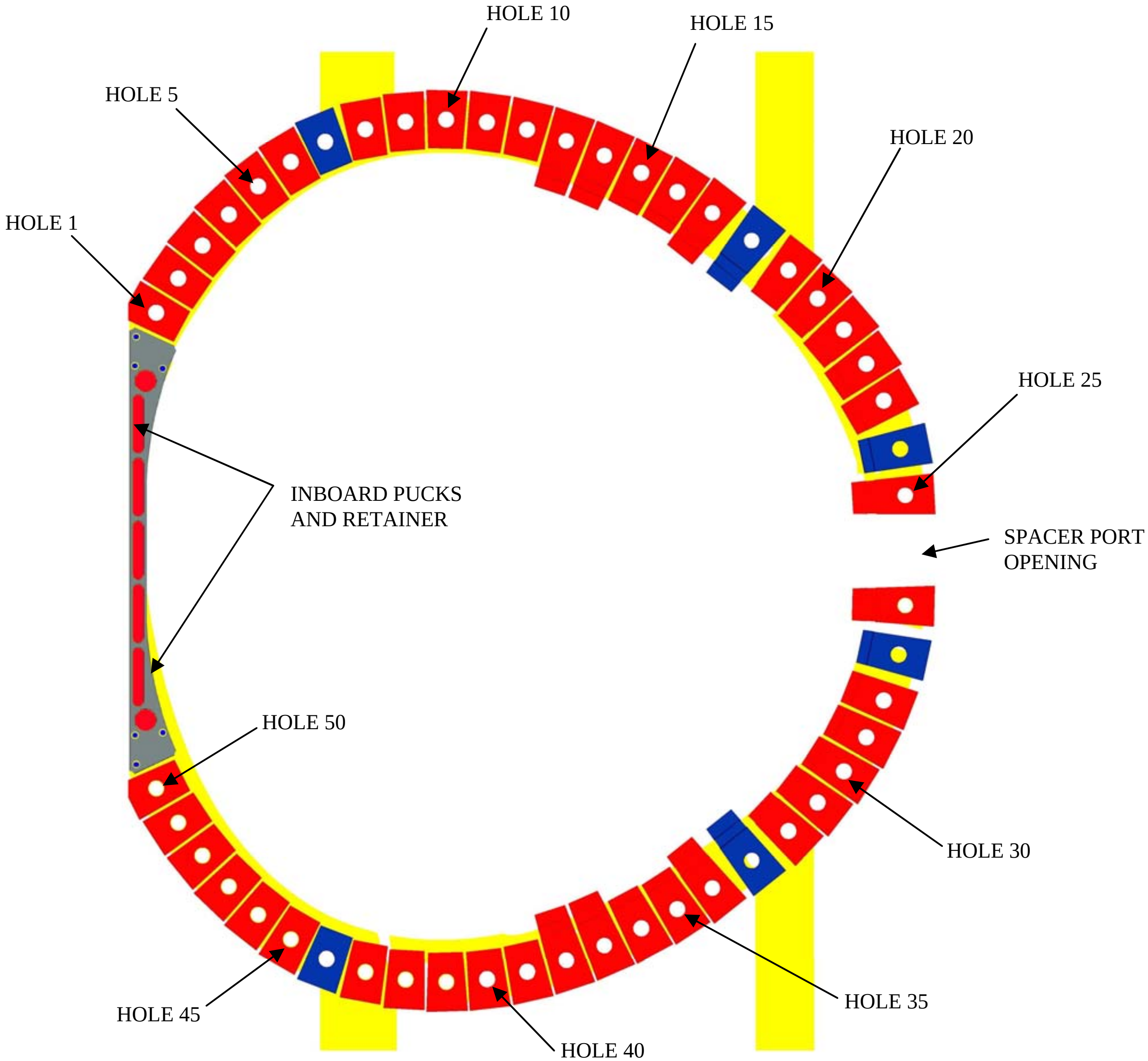
DETAIL A
SCALE 0.240

Bolted Joint Asm (SE140-190-R3)

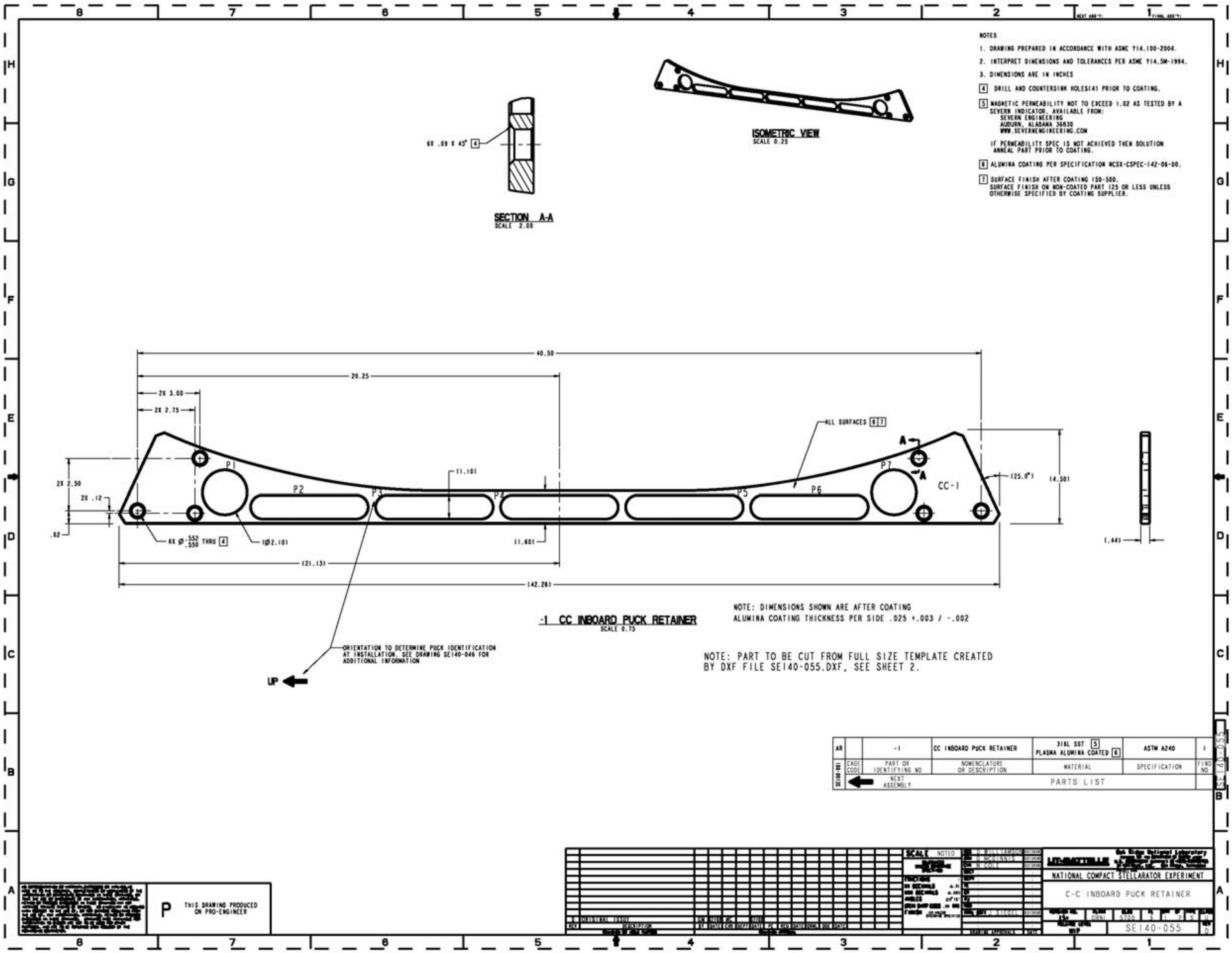


CC Hole #	Shim Length Hole to Bottom	No Bolt Shim
1	2.75	
2	2.75	
3	2.75	
4	2.75	
5	2.75	
6	2.75	
7		2.75
8	2.75	
9	2.75	
10	2.75	
11	2.75	
12	2.75	
13	5.00	
14	5.00	
15	3.75	
16	3.75	
17	5.00	
18		5.00
19	3.75	
20	3.75	
21	3.75	
22	3.75	
23	3.75	
24		3.75
25	5.00	
26	5.00	
27		3.75
28	3.75	
29	3.75	
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	
44		2.75
45	2.75	
46	2.75	
47	2.75	
48	2.75	
49	2.75	
50	2.75	

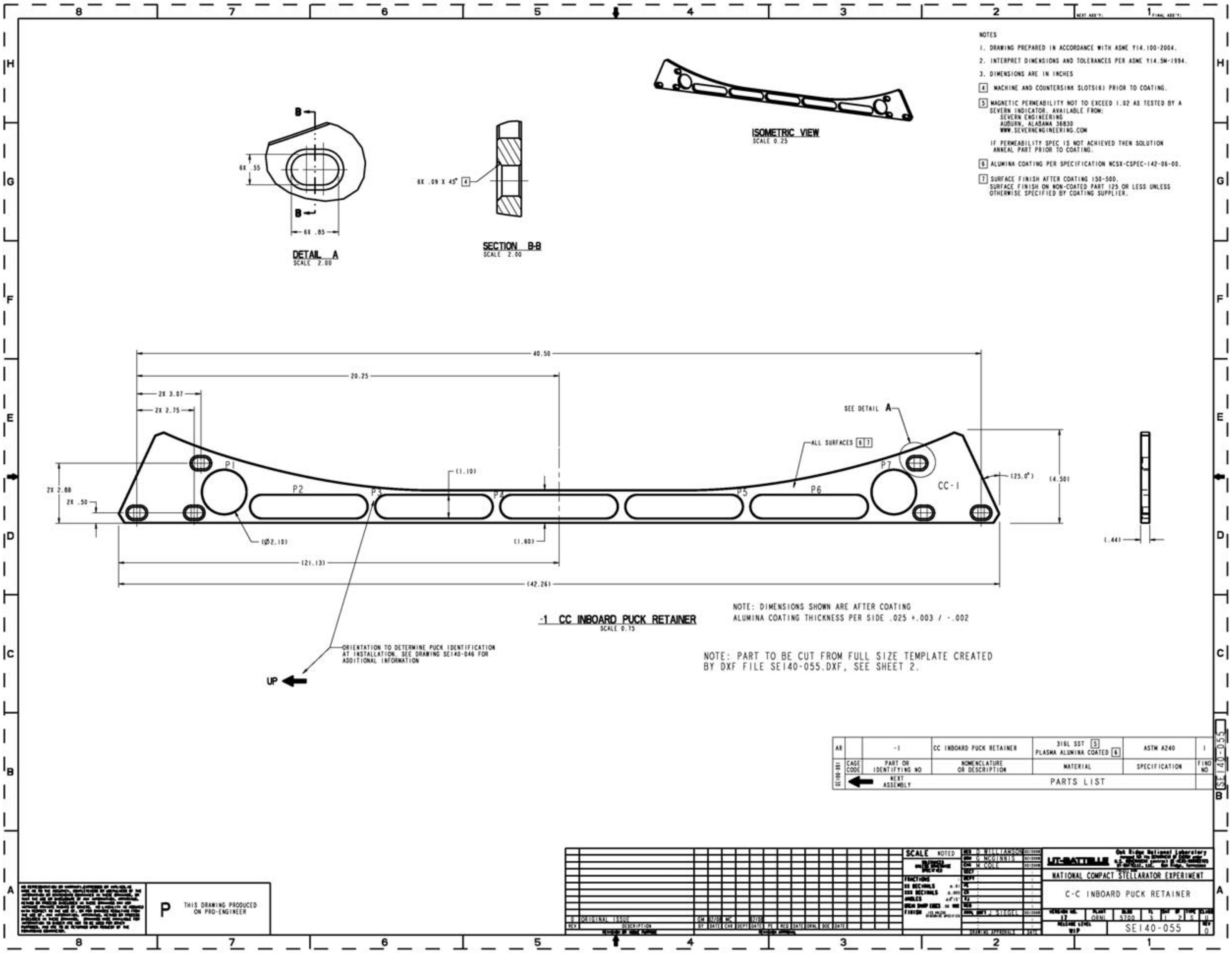
C-C FLANGE



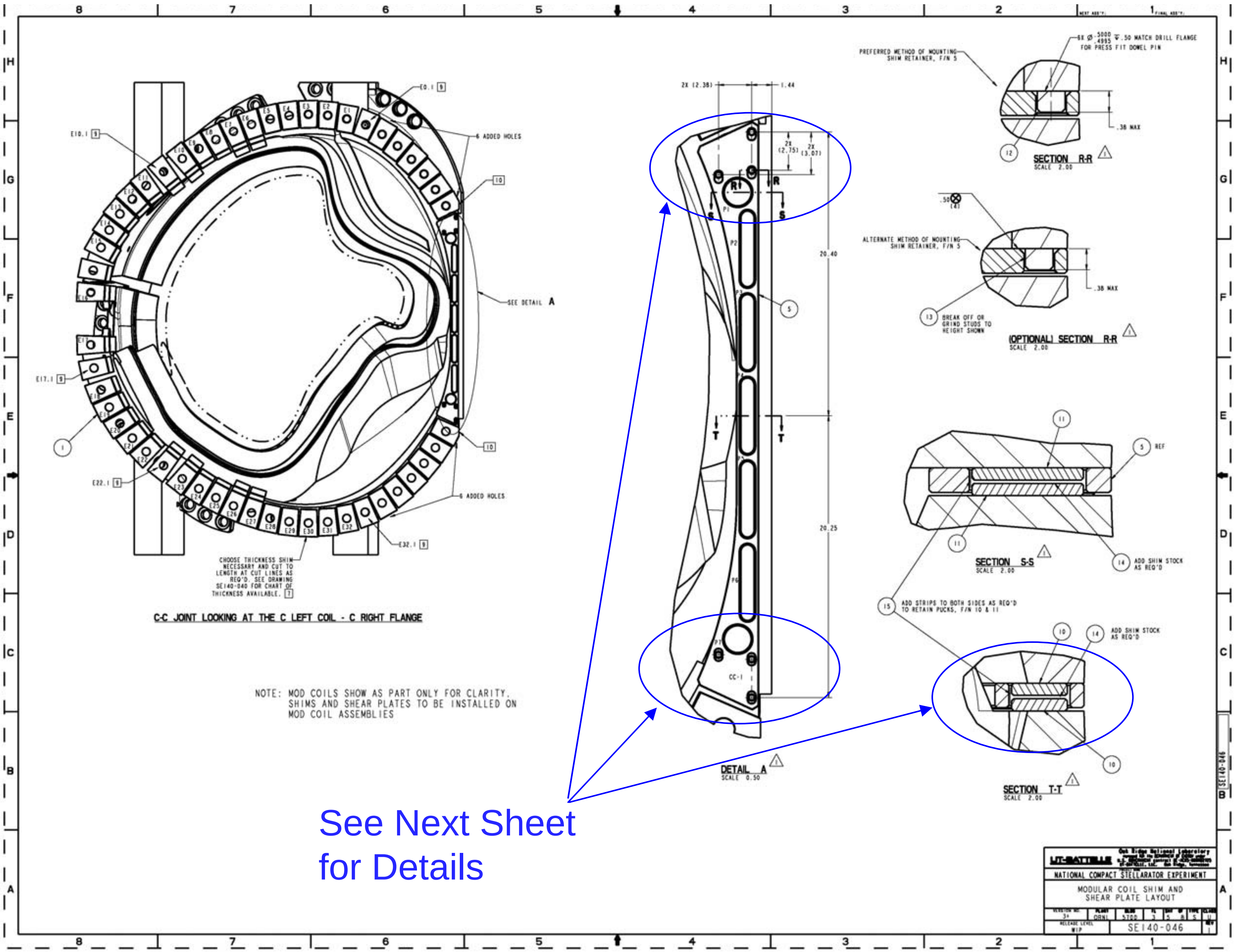
CC Puck Retainer SE140-055



CC Puck Retainer SE140-055



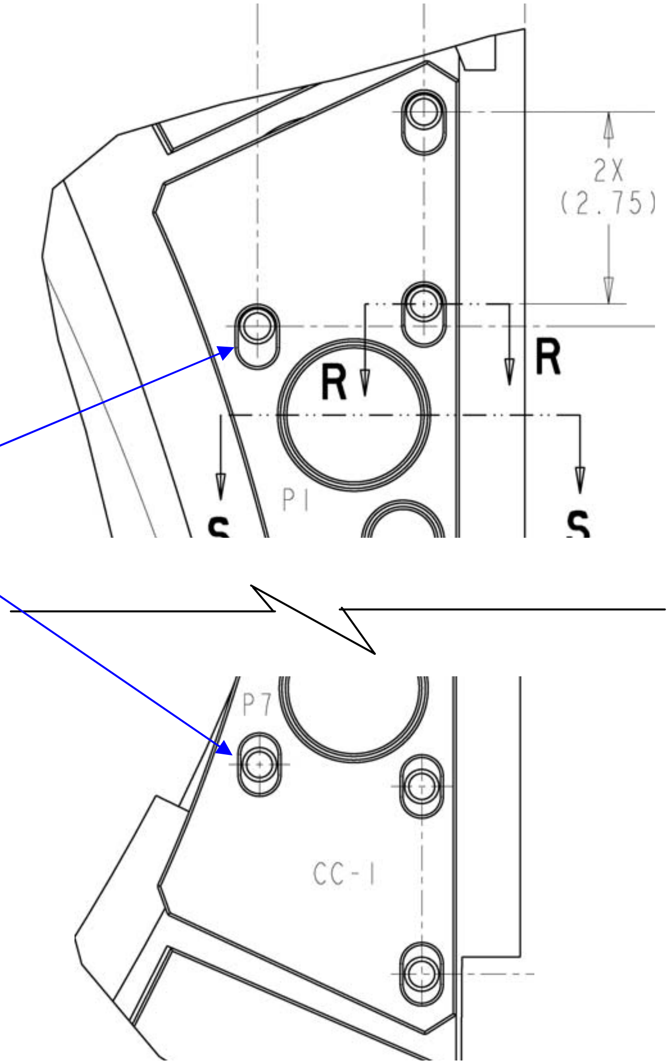
Shim Layout Drawing SE140-046 Sheet 5



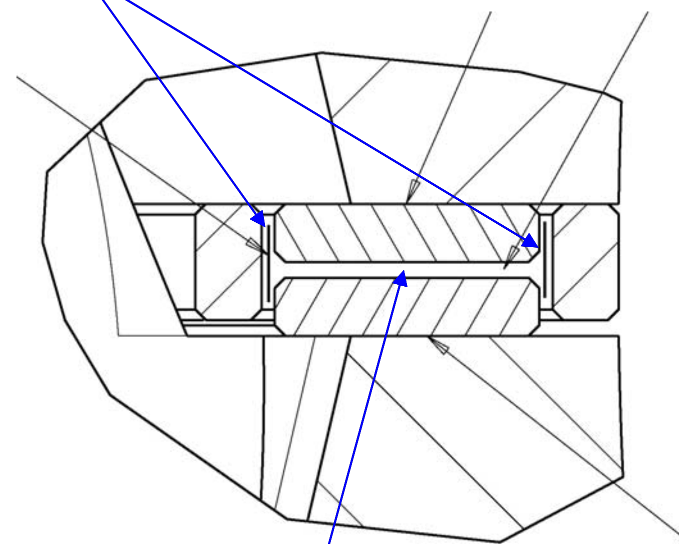
See Next Sheet
for Details

Shim Layout Drawing SE140-046 Sheet 5 (Details)

Slotted Holes Allow Puck Carrier to “Float” Without Adding loads into Pins

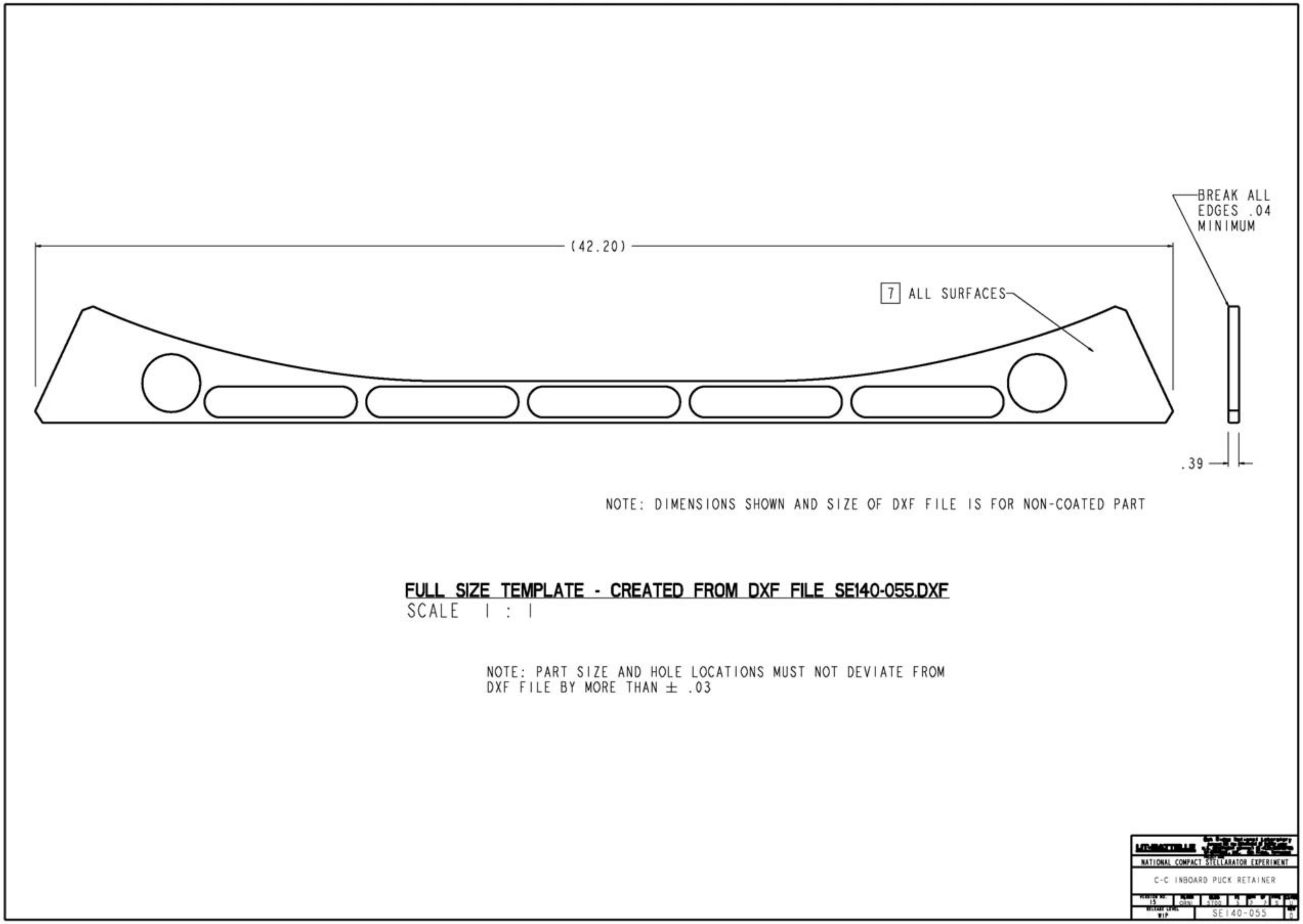


Nomex Strips to be Used for Puck Retention and Centering

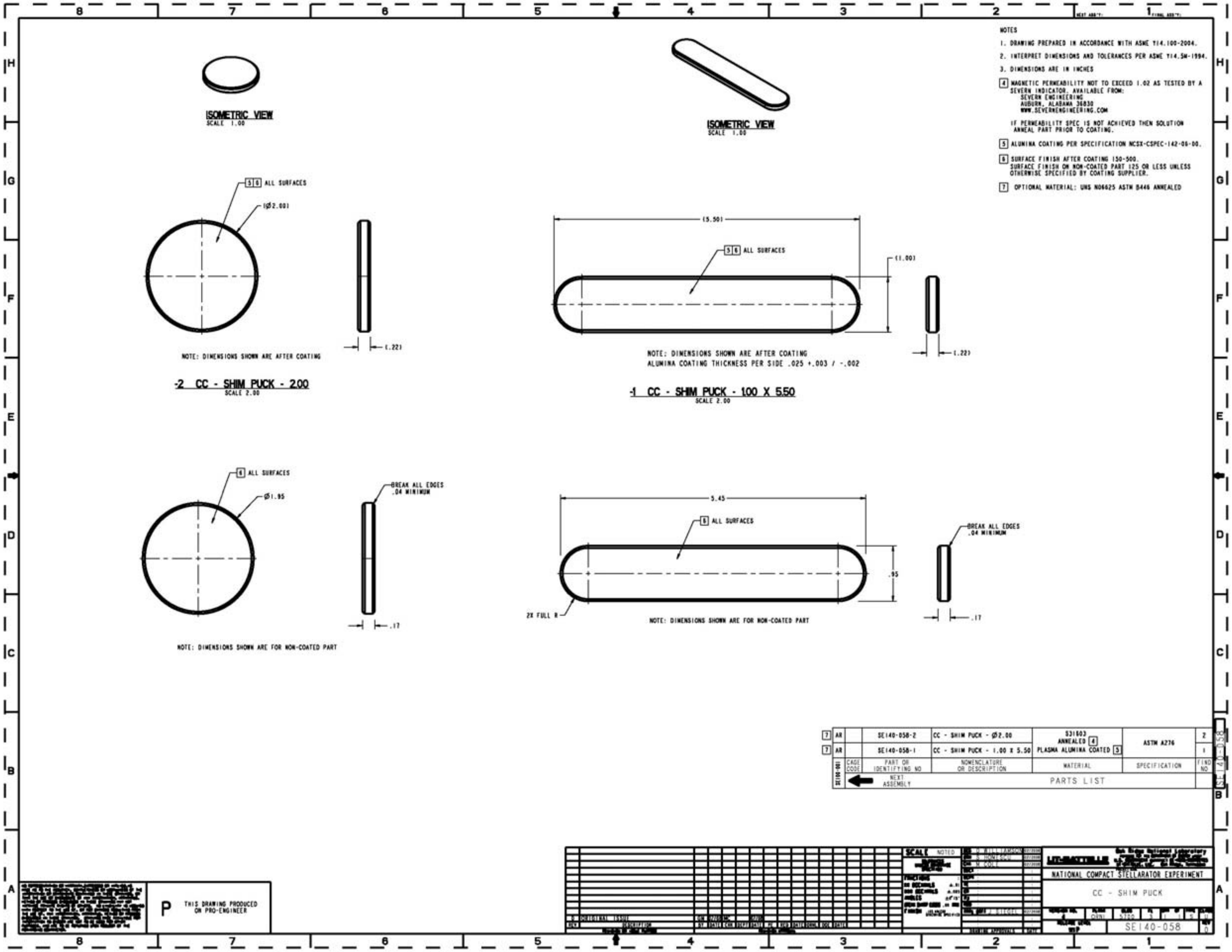


Shim Stock to be Added as Req’d

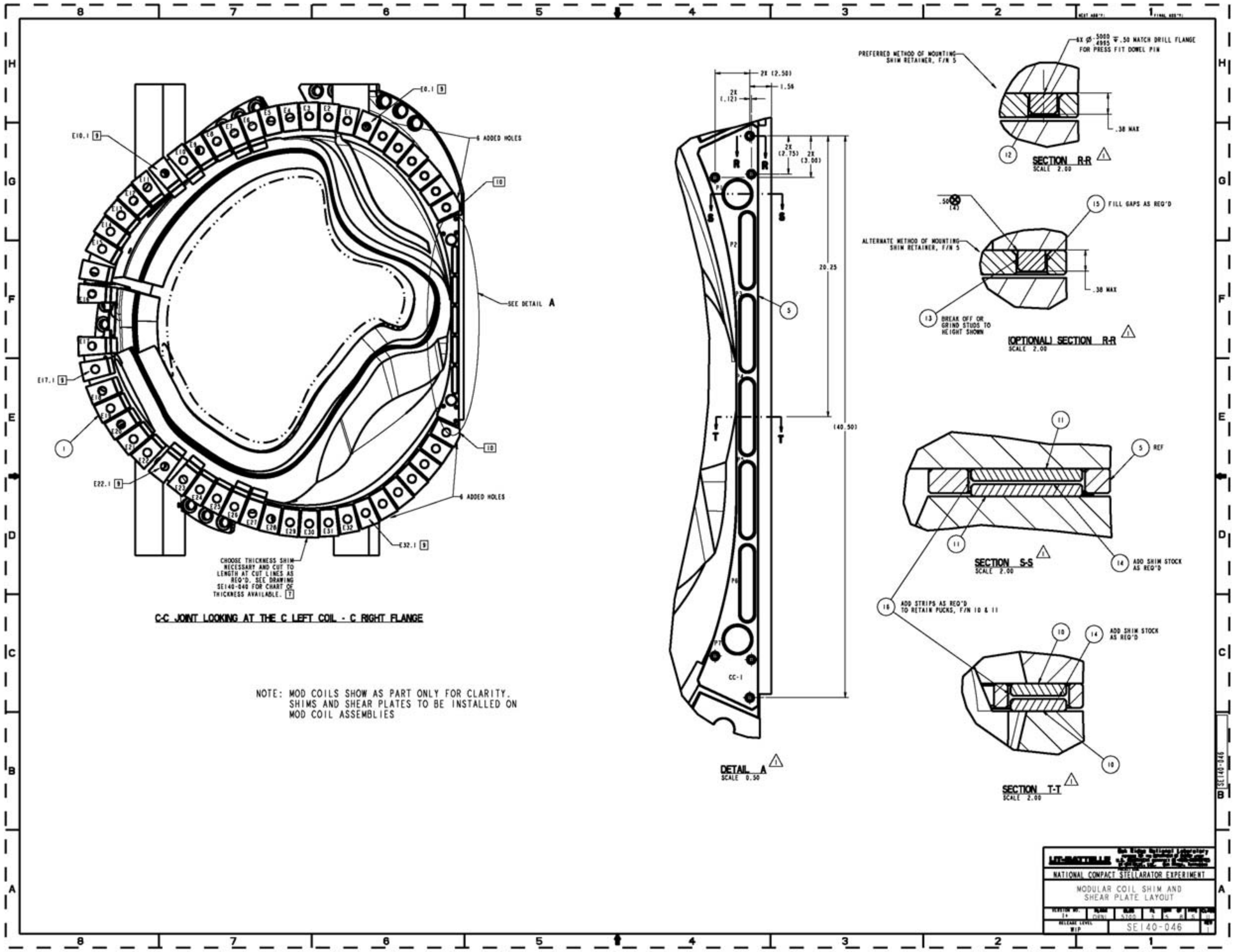
CC Puck Retainer (for DXF) SE140-055 Sheet 2



CC Shim Pucks SE140-058

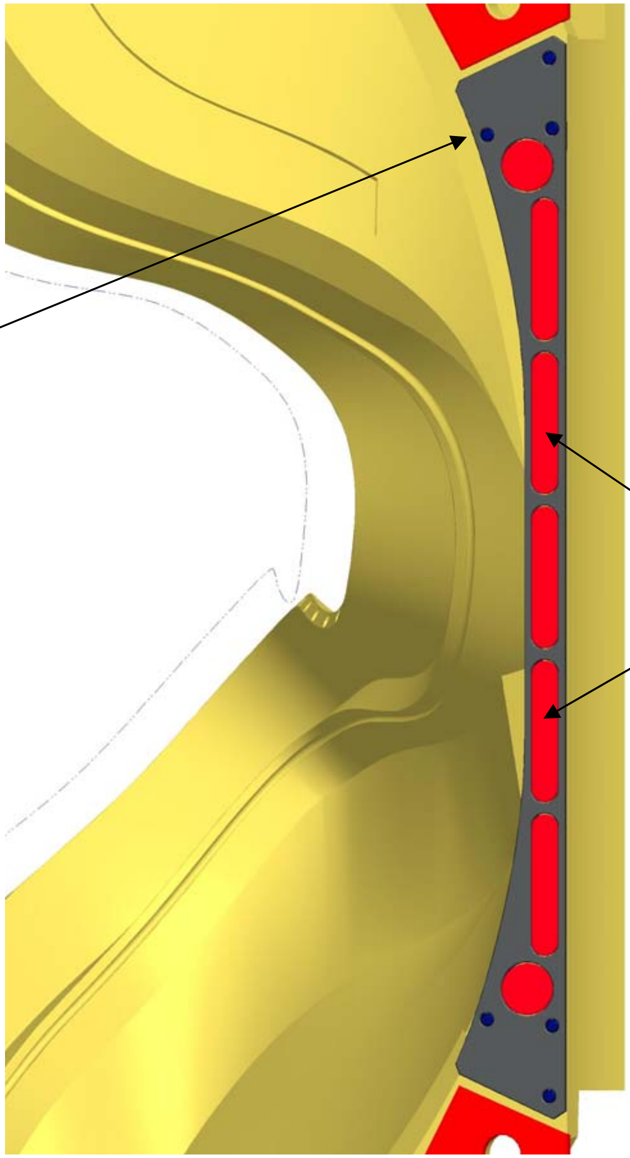


Shim Layout Drawing SE140-046 Sheet 5



CC Inboard Pucks Installed

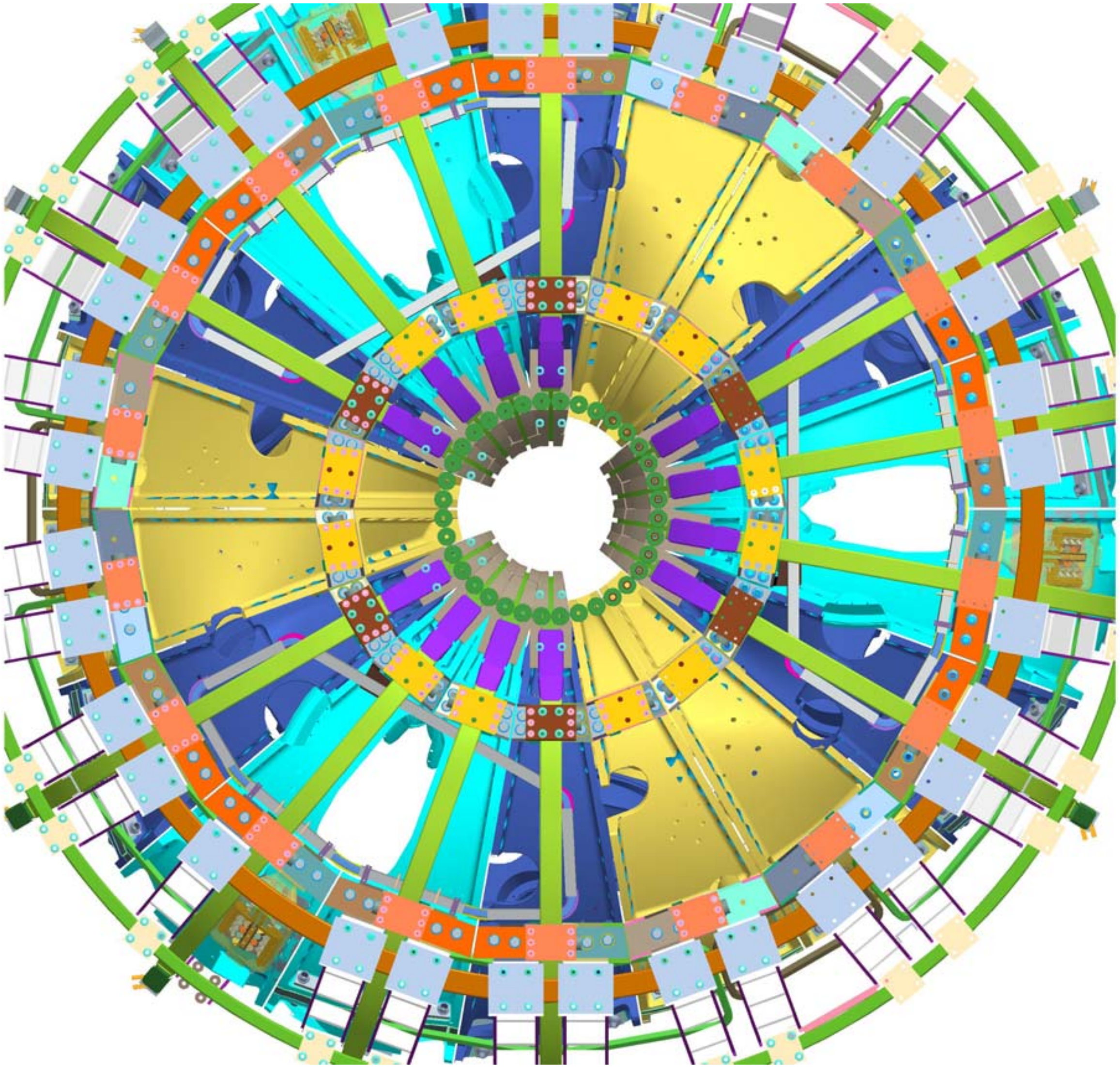
SE140-055 Retainer positioned with 3 pins each end



Alumina coated compression pucks

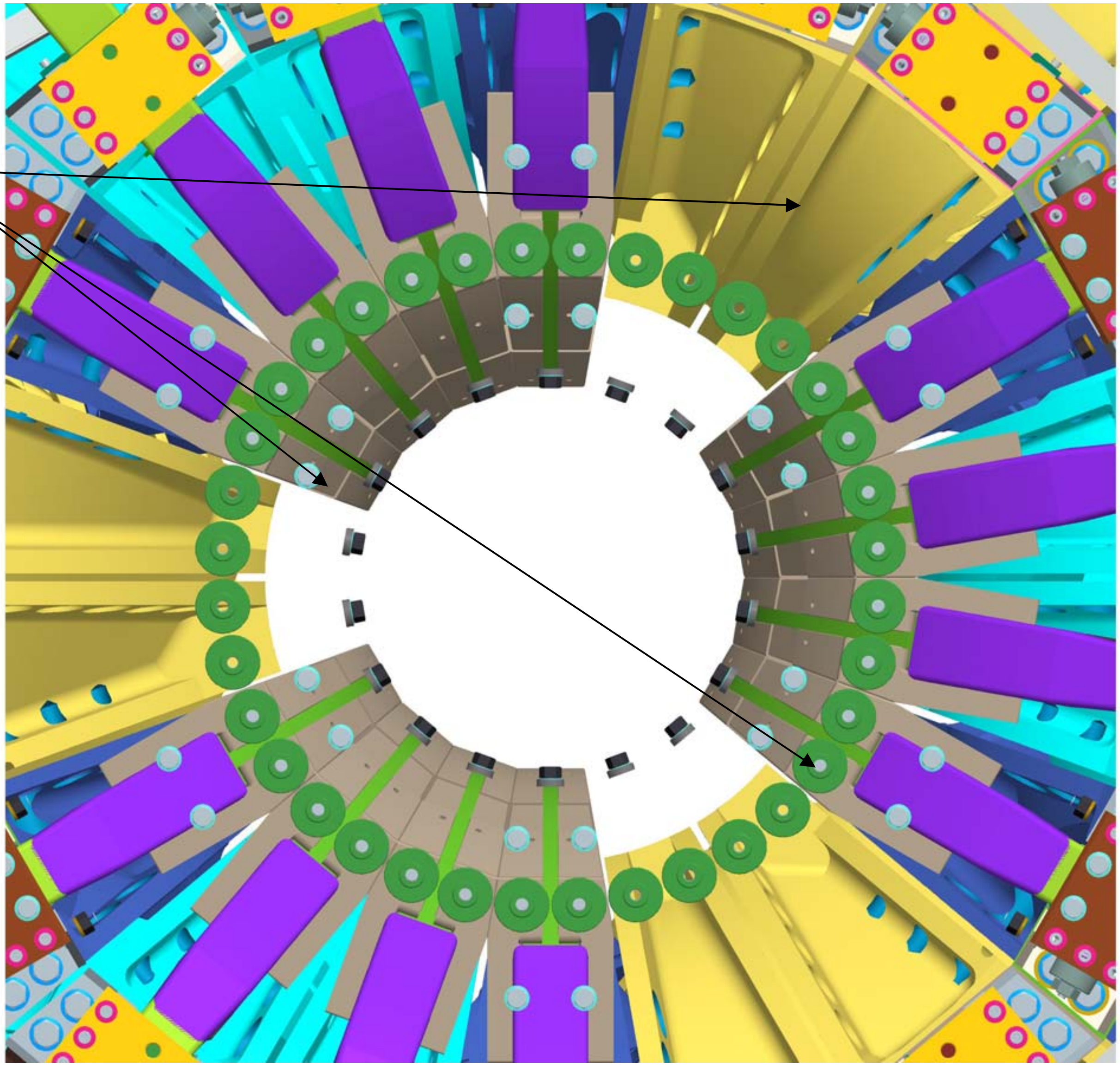
C to C ASSEMBLY

Top View as 3 Field Periods Will be Assembled



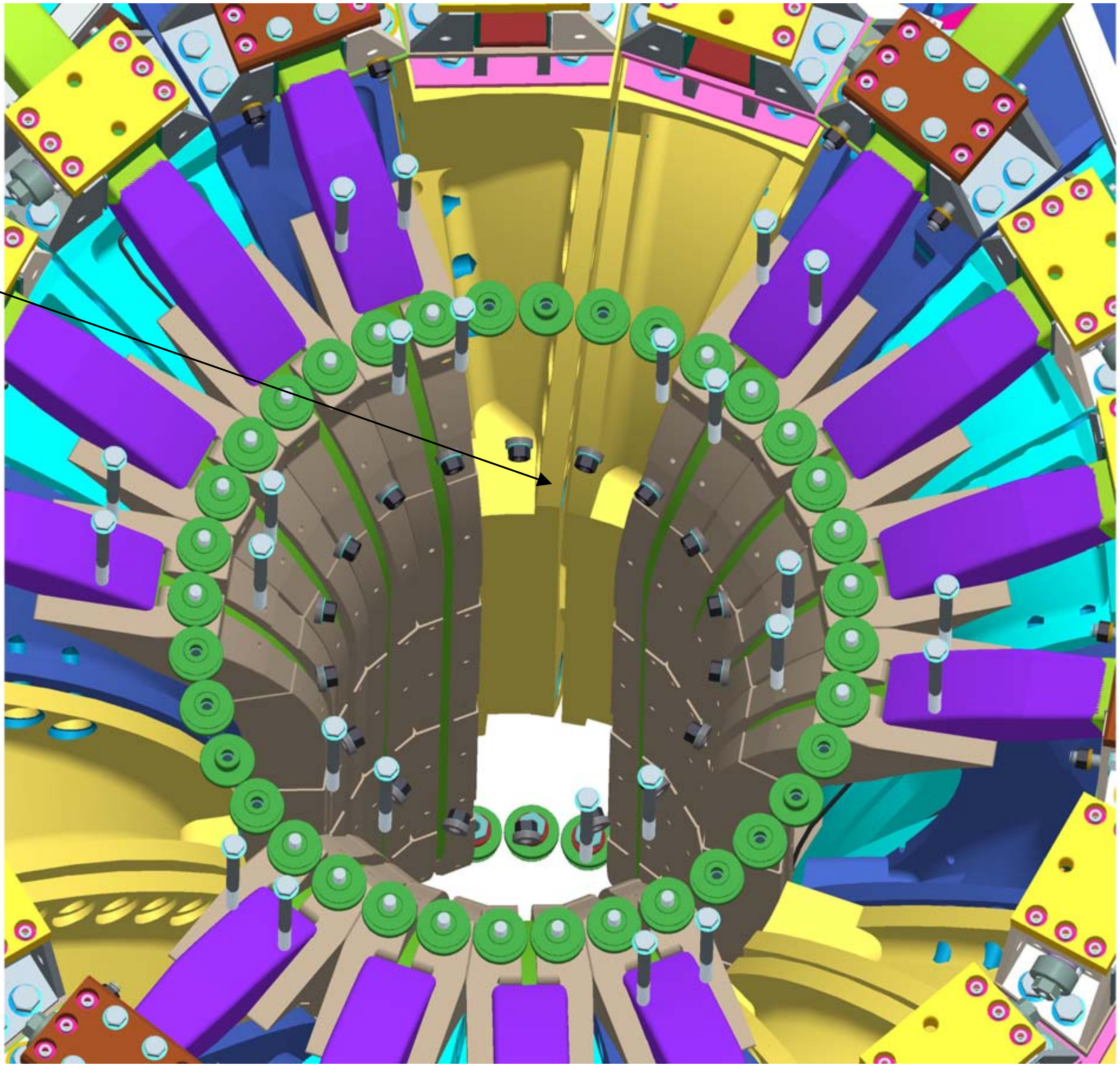
C to C ASSEMBLY

Access to the 3 CC Joints



C to C ASSEMBLY

Area to
Measure CC
Inboard Pucks

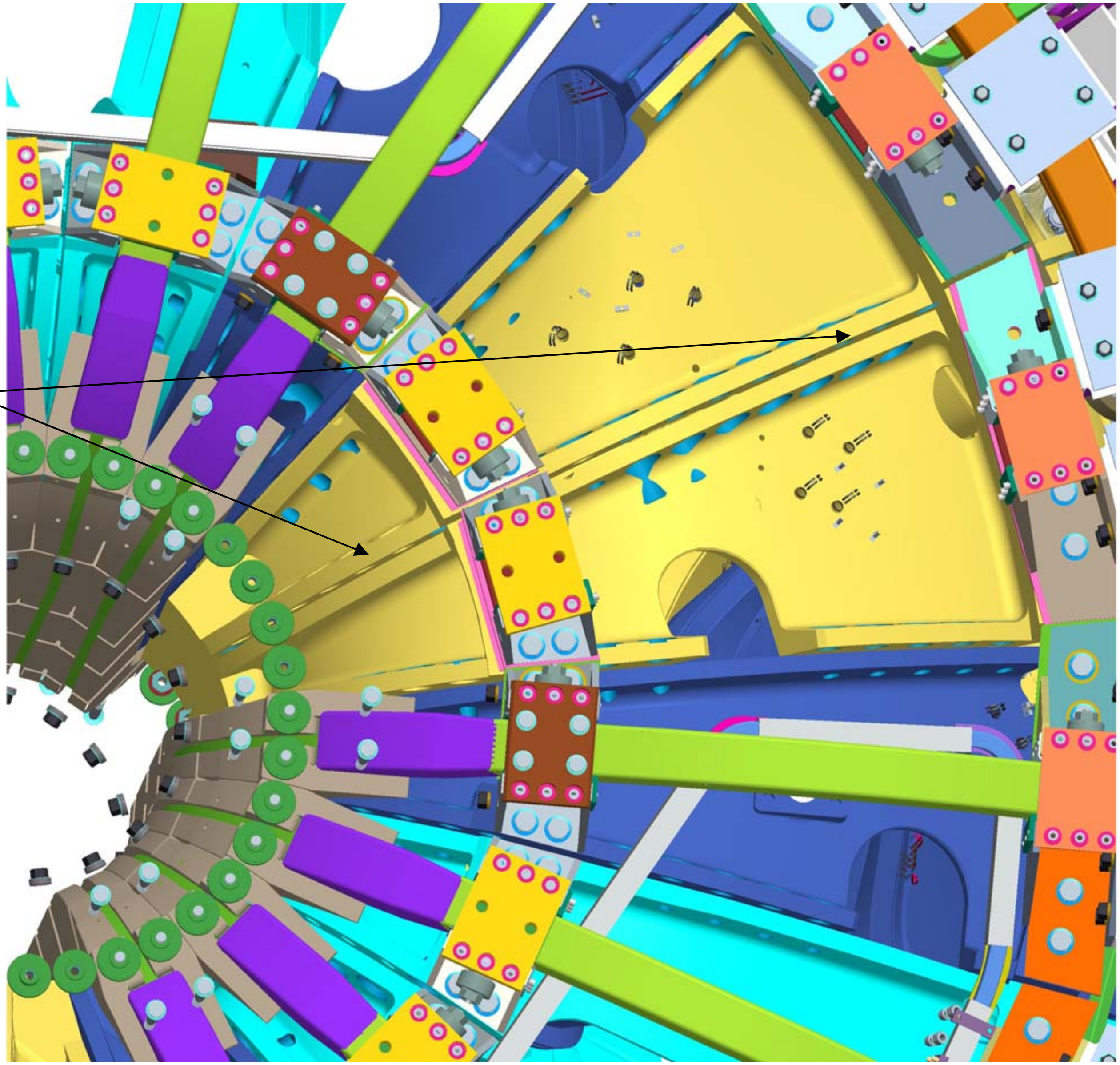


C to C ASSEMBLY

We've Found the PERFECT Guy to do the Measurements!!

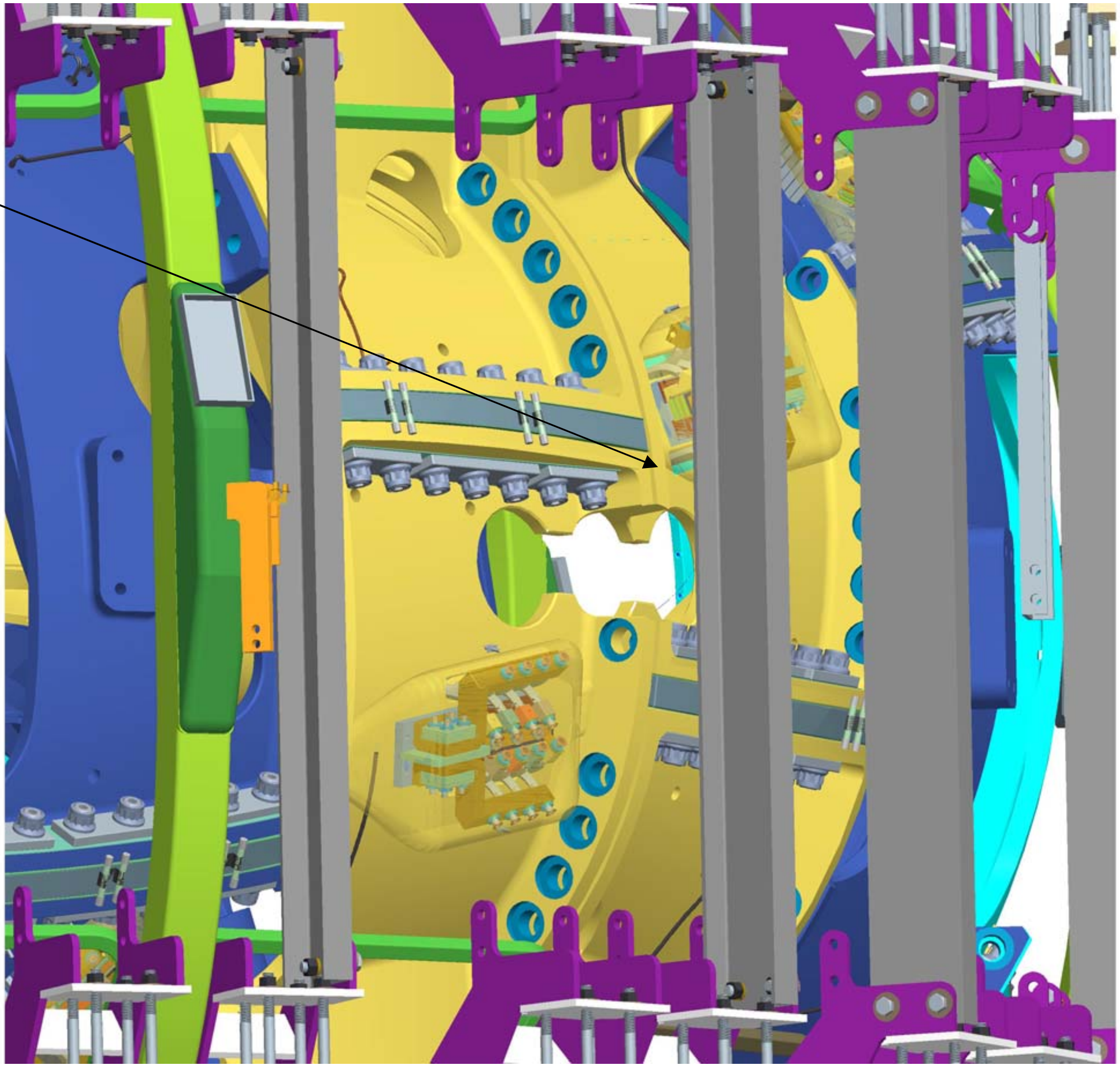
C to C ASSEMBLY

With the TF and Trim Coils over the C Joint Not Installed Yet We have Good Access to Measure and Wiggle Outboard Shims



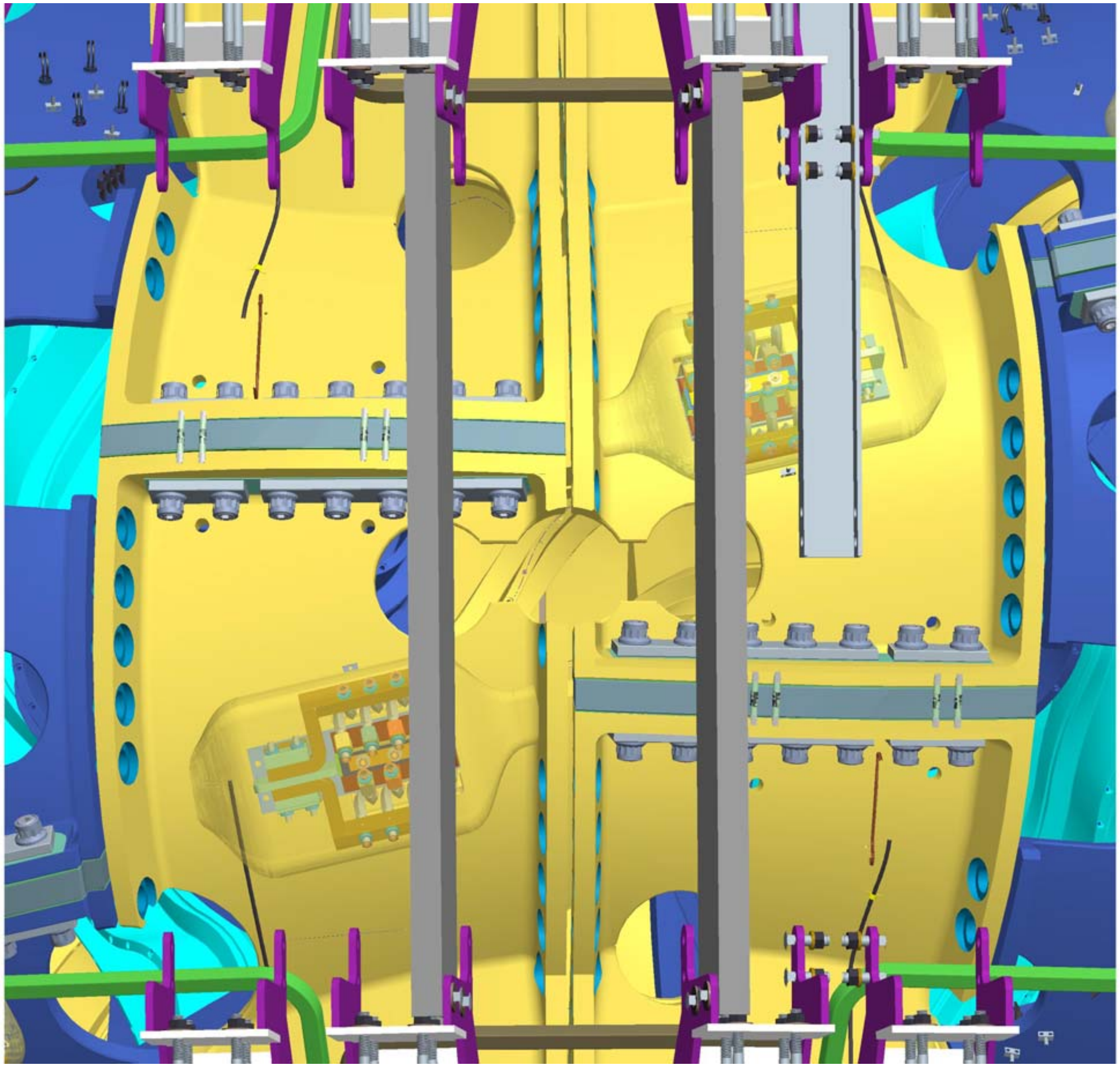
C to C ASSEMBLY

Good Access Under Support Structure



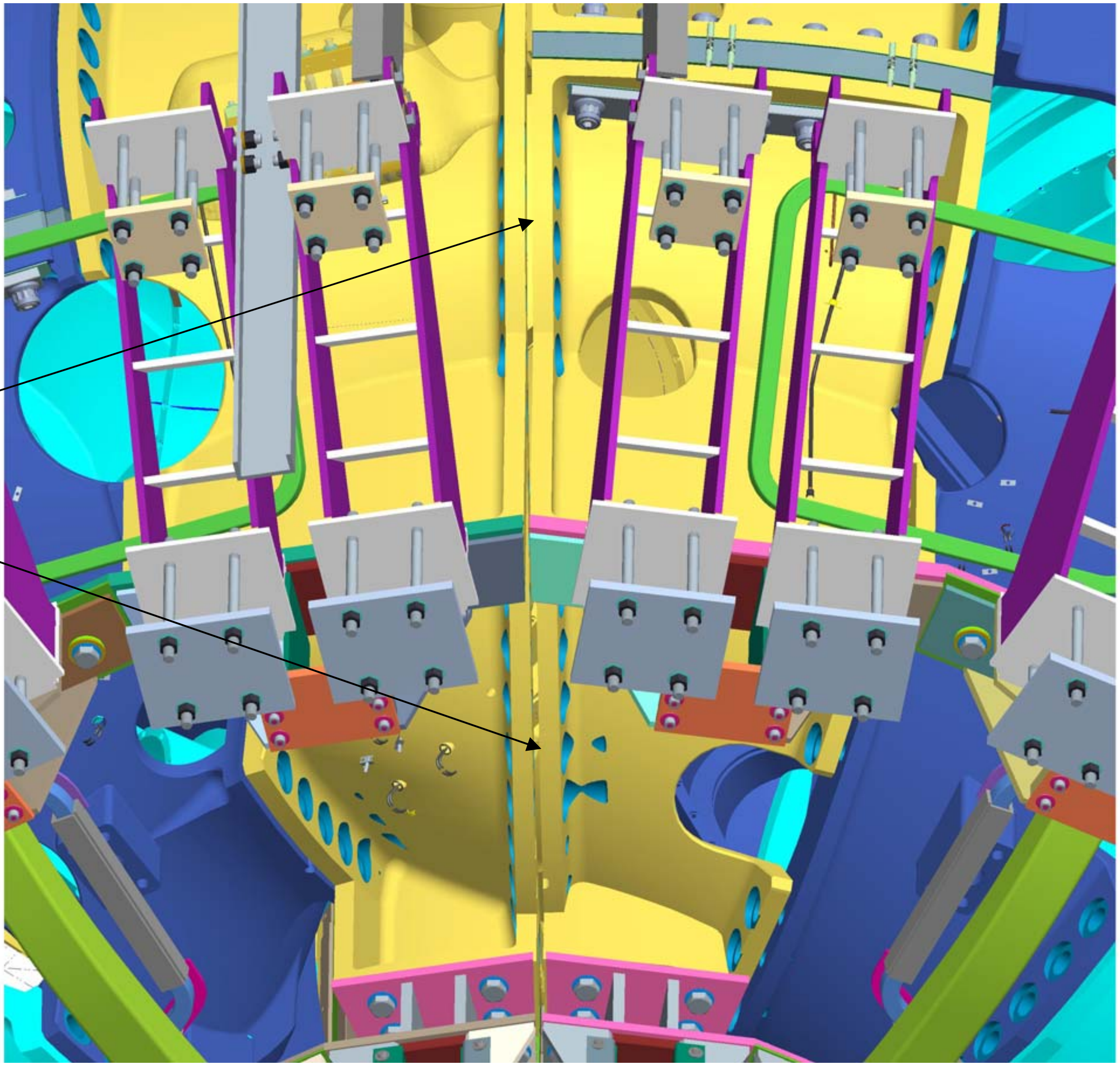
NCSX National Compact Stellarator Experiment

View Outside
Near Midplane



C to C ASSEMBLY

Access to
Lower Joint
Area



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

Paul Fogarty will present the Access Study

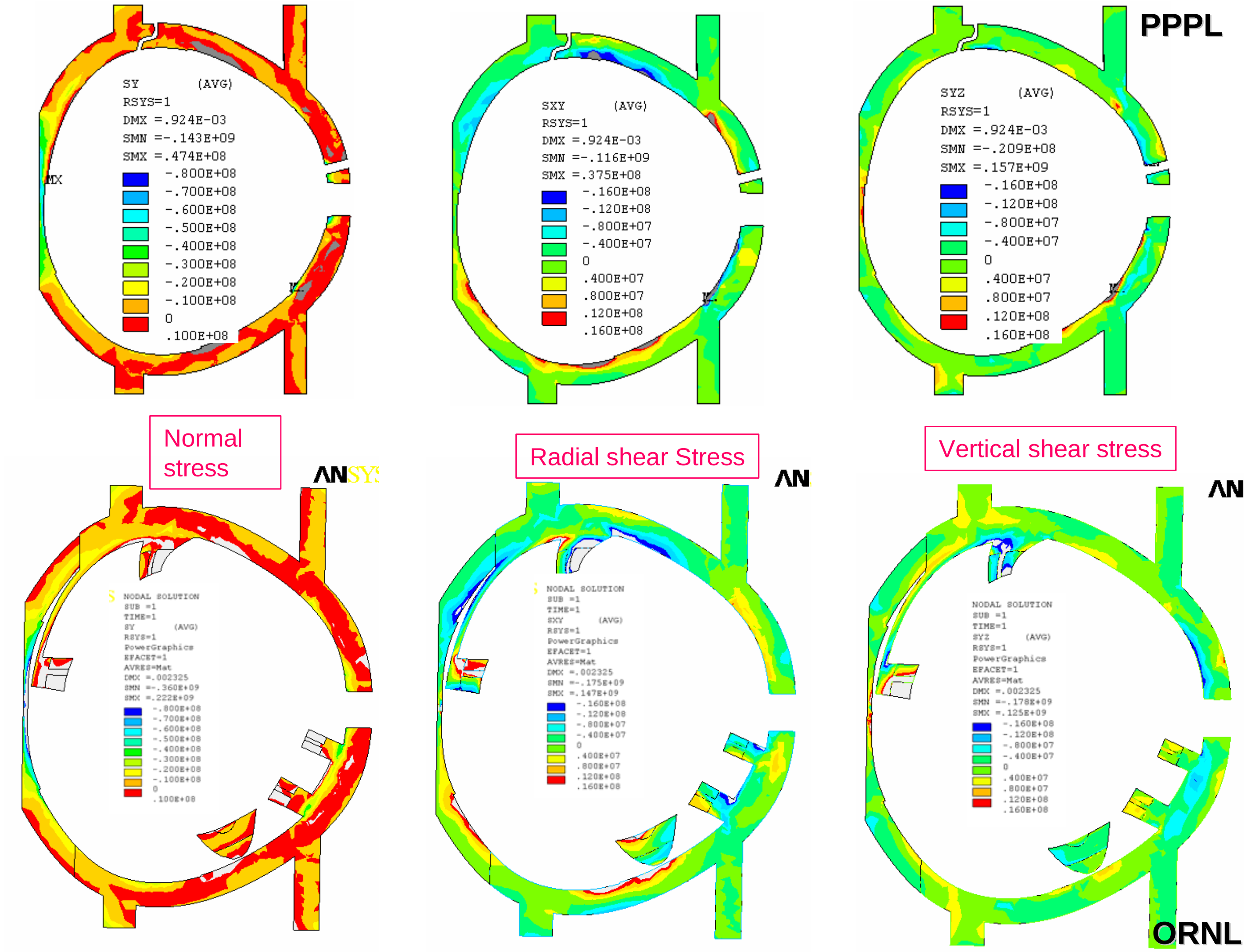
Structural Analysis

K Freudenberg

Includes:

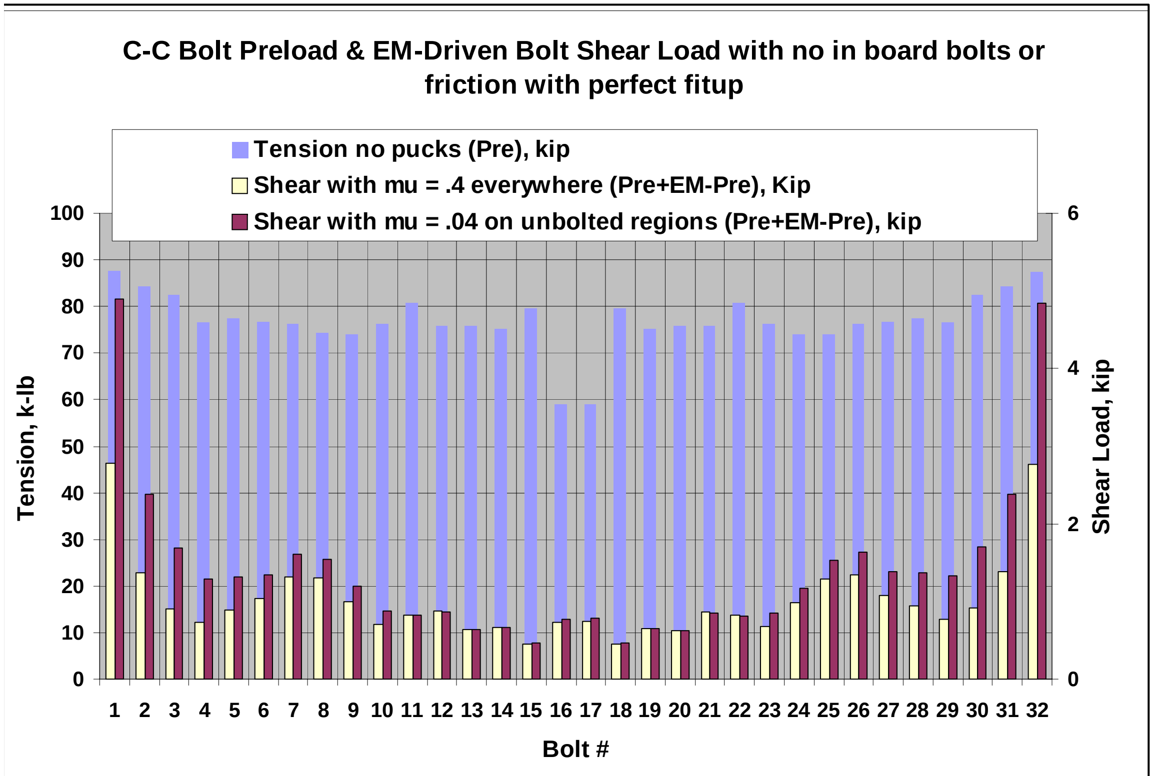
- Twelve additional bolts added to the outboard region
- Inner leg carrier plate and compression pucks

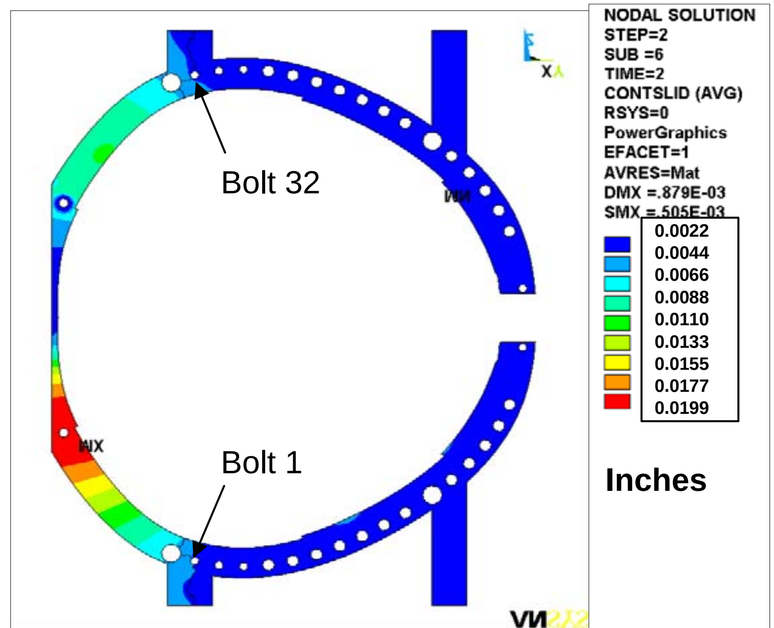
CC Previous work (completely bonded flanges)

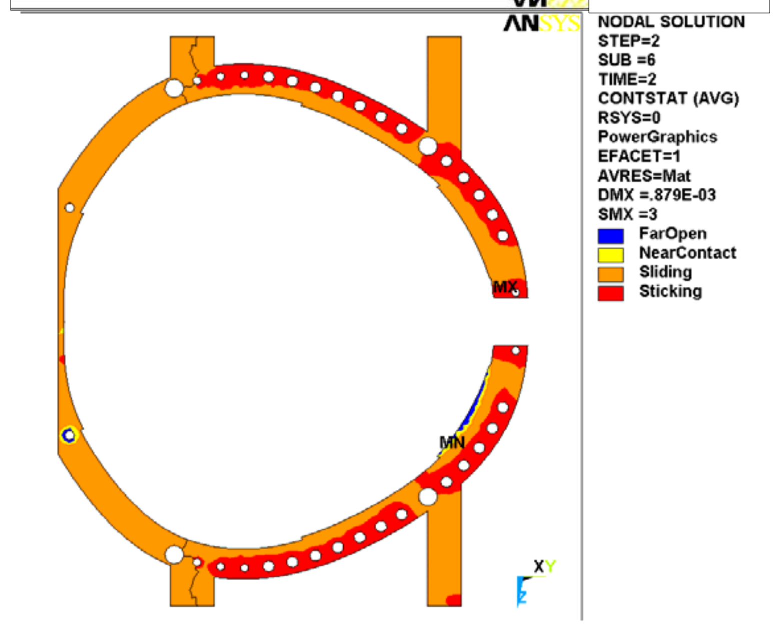


As shown in the first picture form the left, the compressive stress is largest near the midplane, This has all of the available area taking the compression.

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







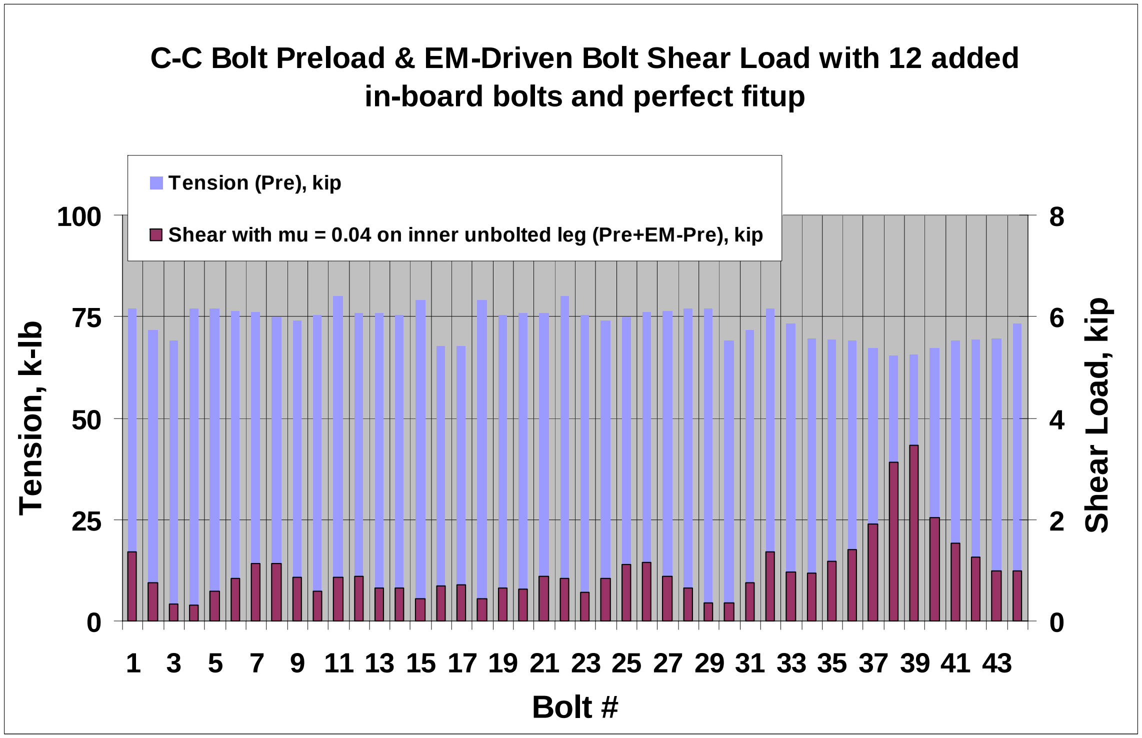
No Inboard Bolt Friction

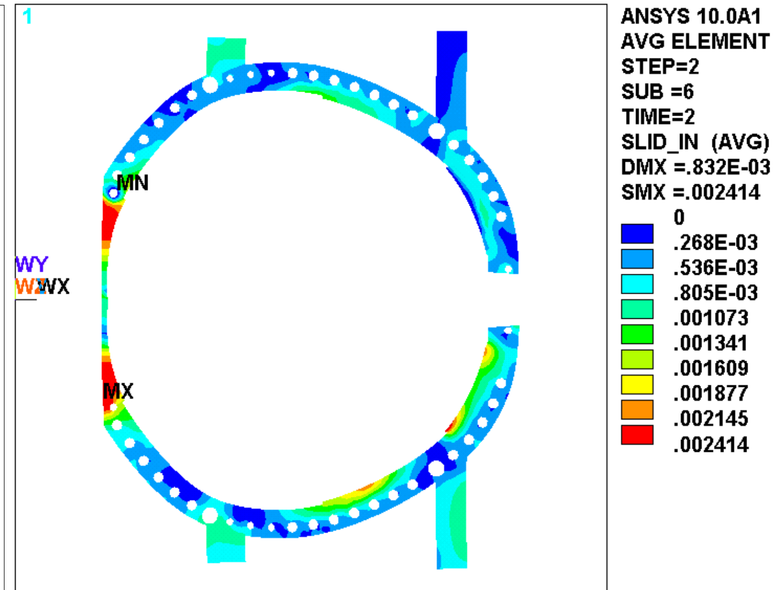
Frictionless In board leg

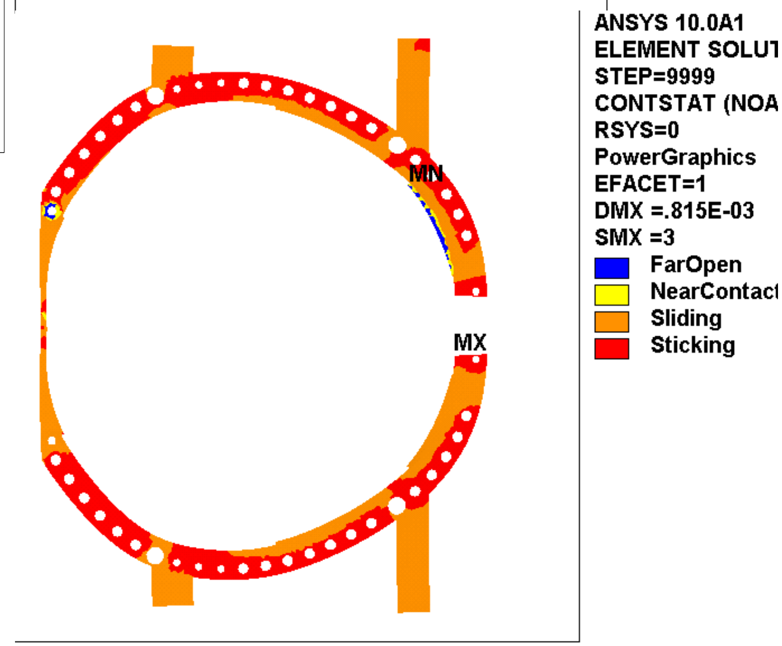
Peak Shear is 4.8 Kips

Sliding is 19 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

Latter results show peak shear is overestimated due to low contact stiffness

Max Sliding and Bolt Shear Table

Inboard Friction	# of inboard bolts	Max sliding distance (in)	Max Shear Force (kips)
0.4	0	0.0065	2.8
0.4	6	0.0047	2.4
0.4	12	0.0011	2.7
0.04	0	0.0199	4.9
0.04	6	0.0143	4.5
0.04	12	0.0024	3.5
Imperfect Fit-up gap of .005" on unbolted region	0	0.0193*	3.3

*sliding occurs after gap has closed

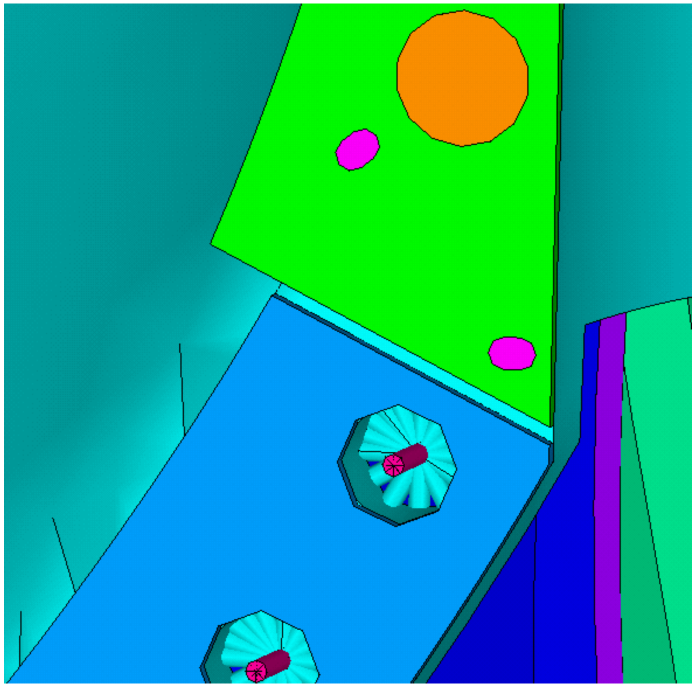
A latter analysis showed that the shear load on the bolts was overestimated (approx 2X) due to a low contact stiffness value which caused shear to go in the bolts. (note: very little effect on slippage)

***** The design solution was to go with 12 added bolts.**

General Comment: Having loose fitting parts is a challenge to model and analyze and thus, a limiting contact approach is adopted. That is, the analysis assumes full contact between the carrier plate and studs and not slotted holes.

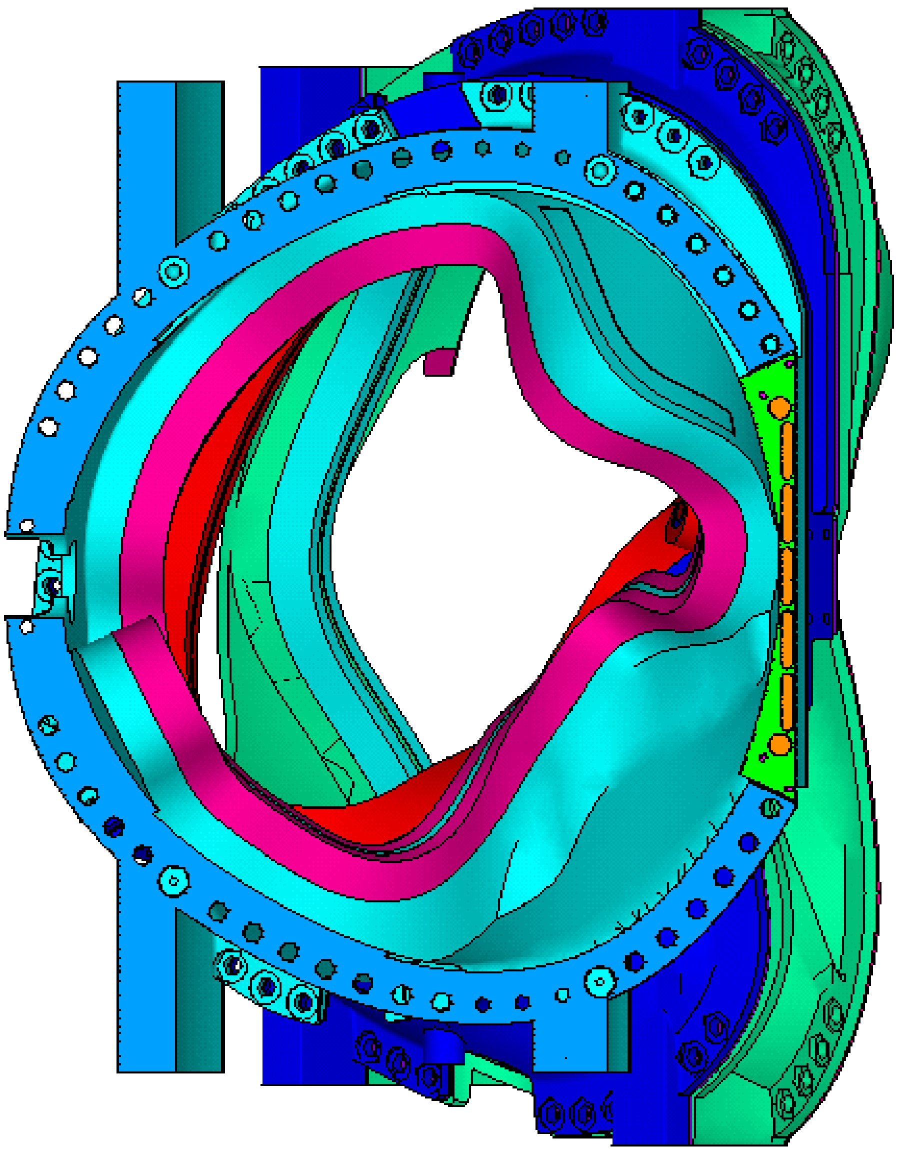
Four Analysis Configurations:

1. Frictionless pucks with outboard bolts – worst case for outboard connection. If all bolts are still, stuck, the outboard will always be "bonded".
2. Friction (mu = 0.4) pucks with bonded outboard flange.
3. Pucks with Coefficient of friction of 0.4 with bonded outboard flange. - no studs
4. Pucks with Coefficient of friction of 0.0 with bonded outboard flange



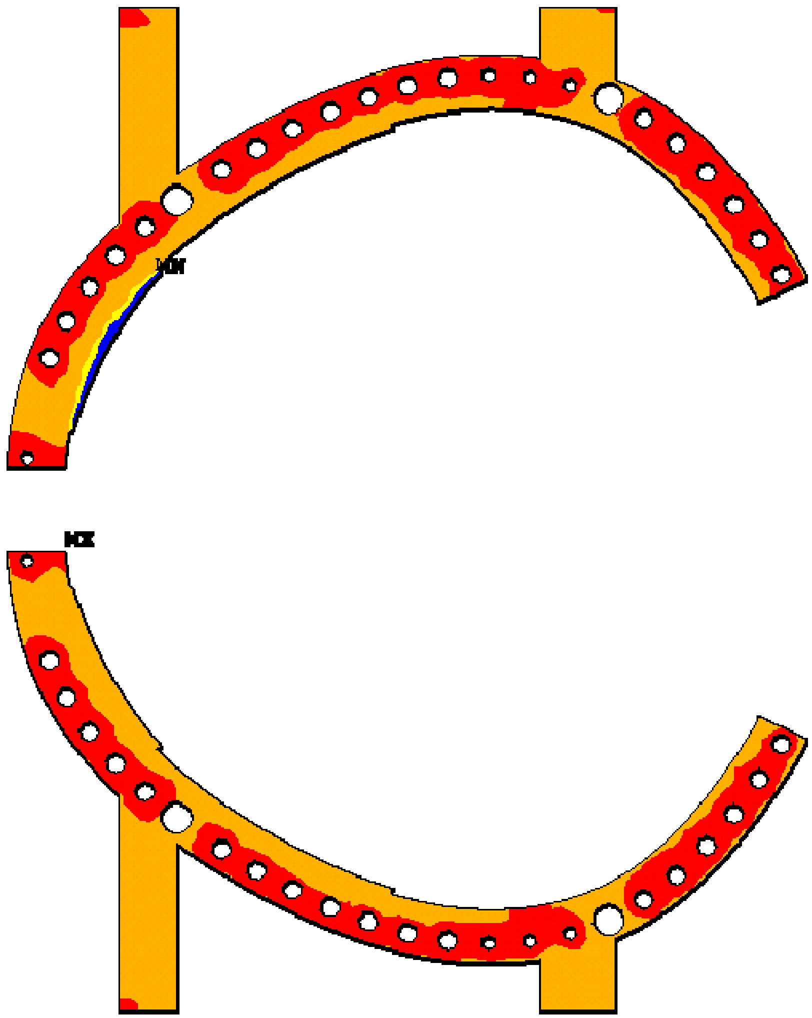
Detail showing the bolts and inner shim

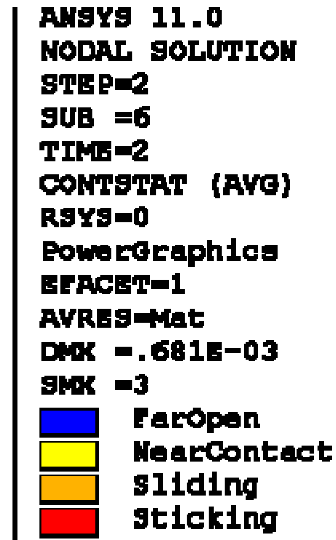
Latest Model - the last piece of the interface puzzle



- New parts added: 4-6 studs, 2 shims, 5 oblong pucks and 2 circular pucks
- Studs are bonded to one C coil and to the shim but not to the adjacent C coil.
- Pucks are bonded to the shims but ride on frictionless surfaces against the C flanges.
- Shims are not connected to the C flanges but are bonded to the studs and pucks.
  - Shims are modeled as 0.5” thick.
- Model can be run with the outer bolts treated as bonded or as discrete bolts (30-40 hr runtime)

Case #1: Contact Status plot for bolts and inner leg compression pucks

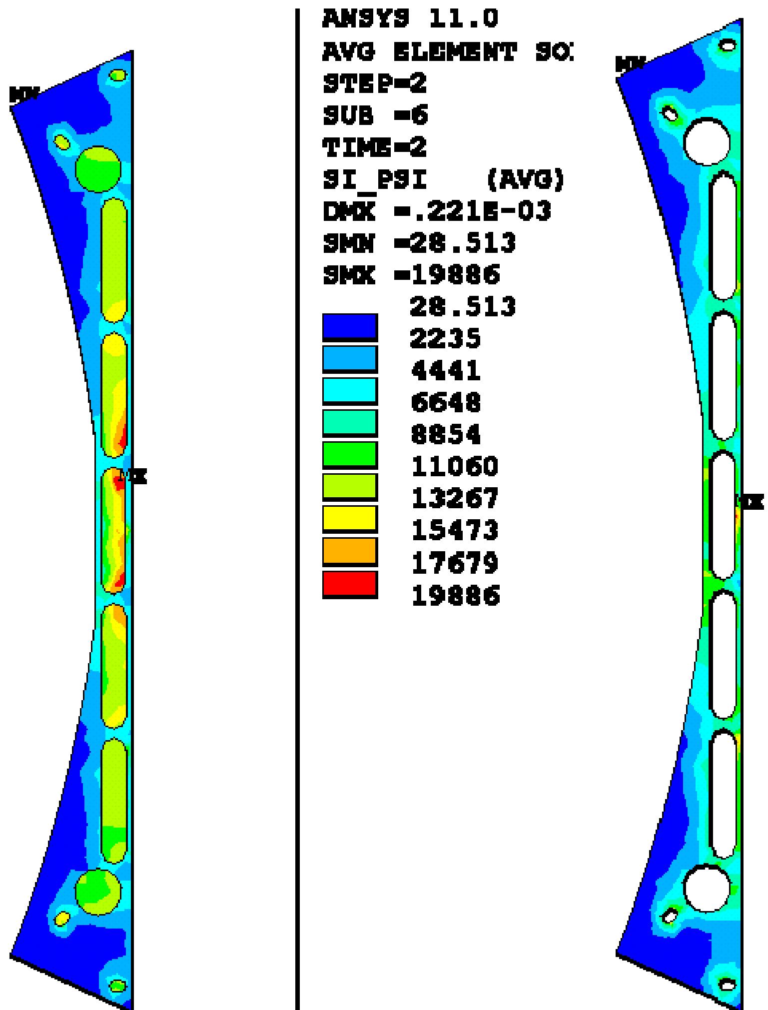




Note preload slightly underestimated on inner bolts. All bolts are stuck.

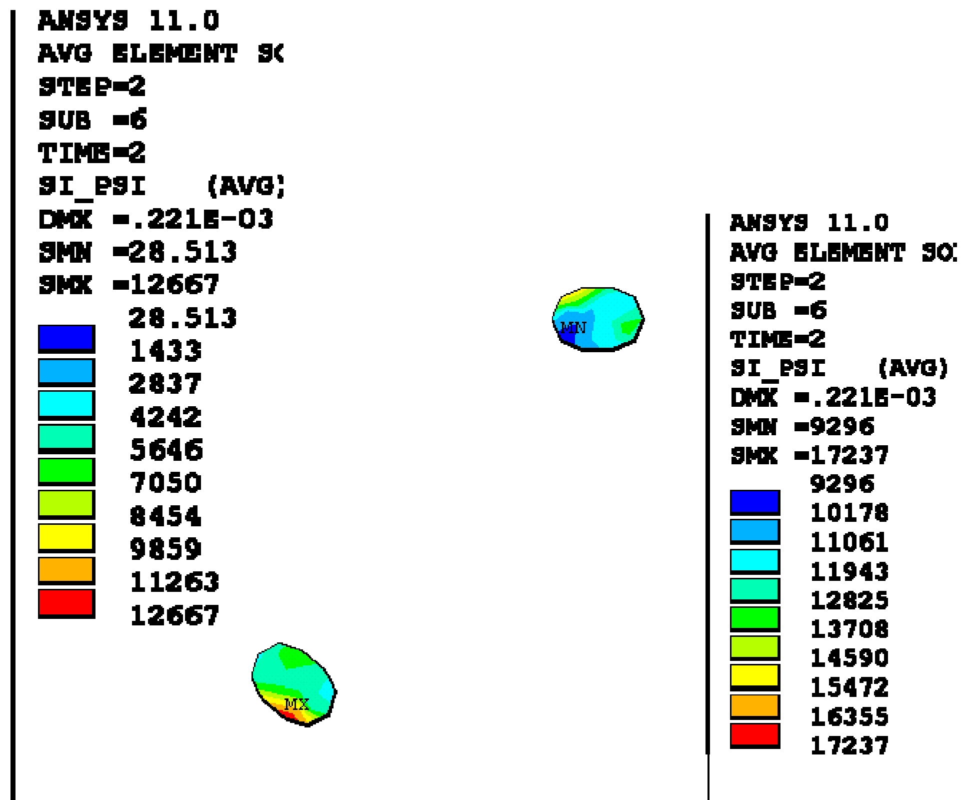
Frictionless inner pucks (keyopt 12 = 0)

Case #1: Stress on inner shim for bolts and inner leg compression pucks



Pucks, carrier and studs stresses

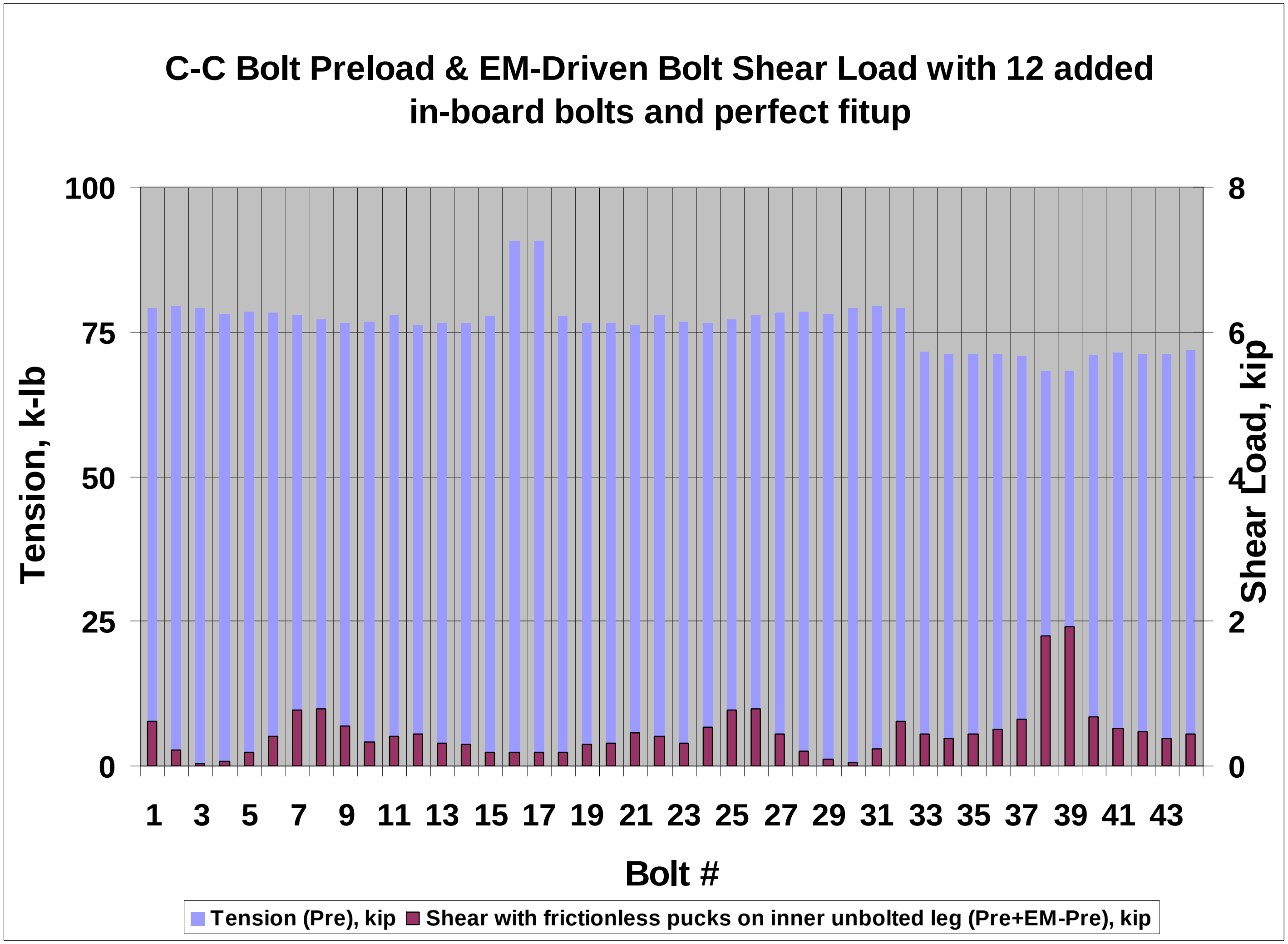
Carrier stresses



Stud stresses

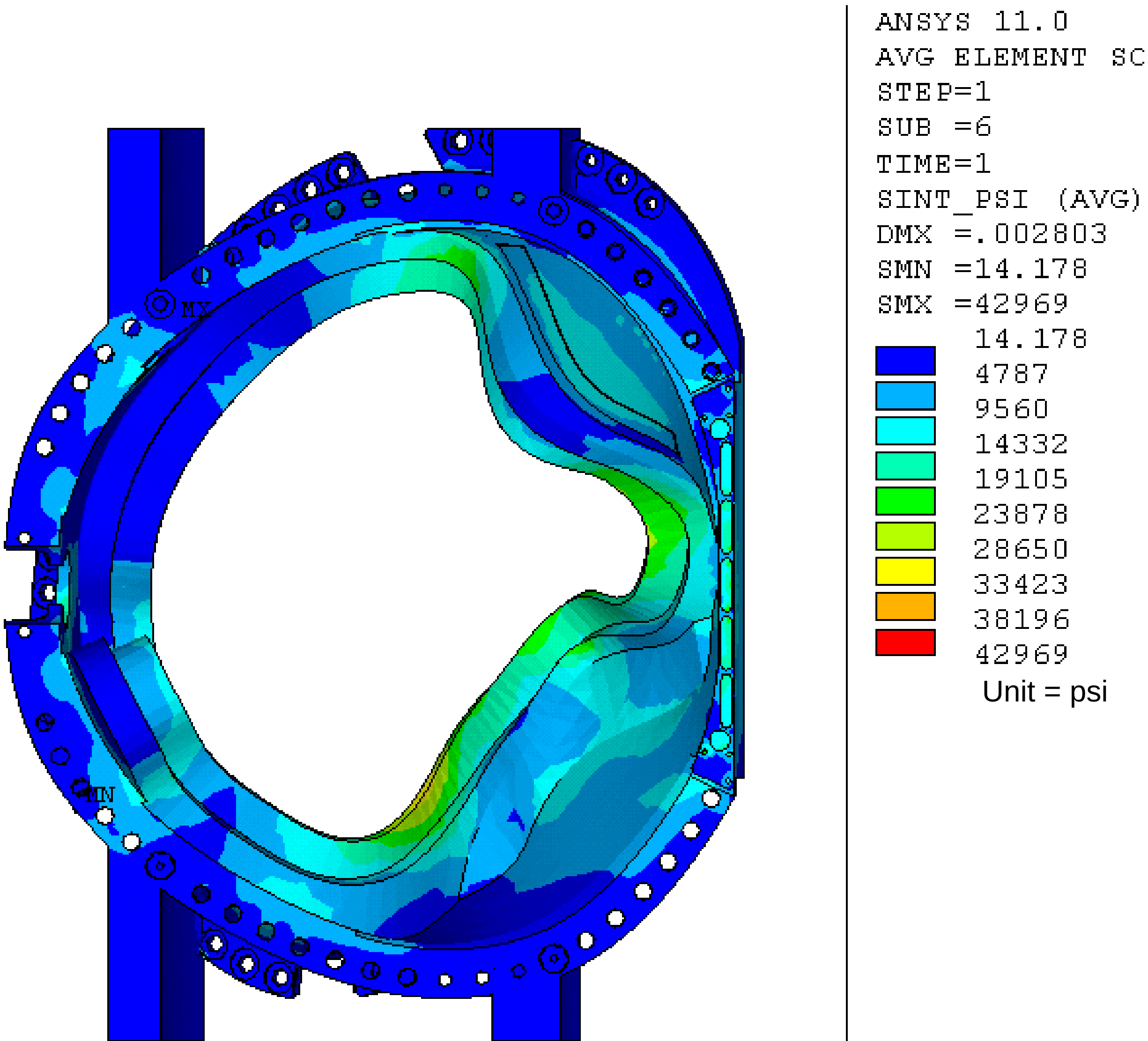
There are no surprises here, the bonded model accurately predicted the stress for the case with the bolts.

Case #1: Bolt preload chart

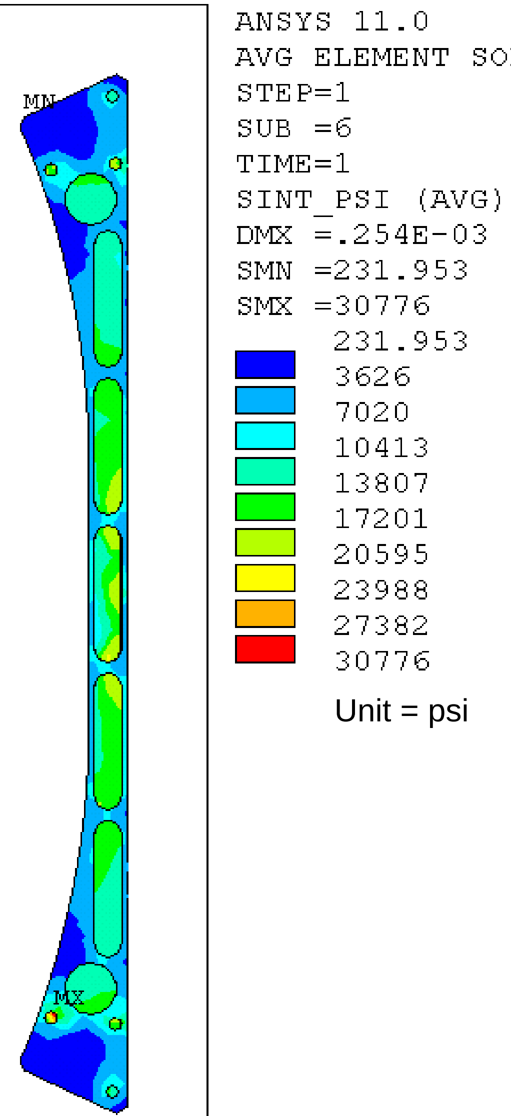


Changing the mesh, caused some overshoot on the outboard bolts and some under estimating on the inboard bolts in terms of preload. All bolts are stuck (approx less than 2 kips/bolt) and any residual shear is caused by stretching of the contact elements as before.

Case #2: Bonded outboard flange – mu = 0.4 under pucks

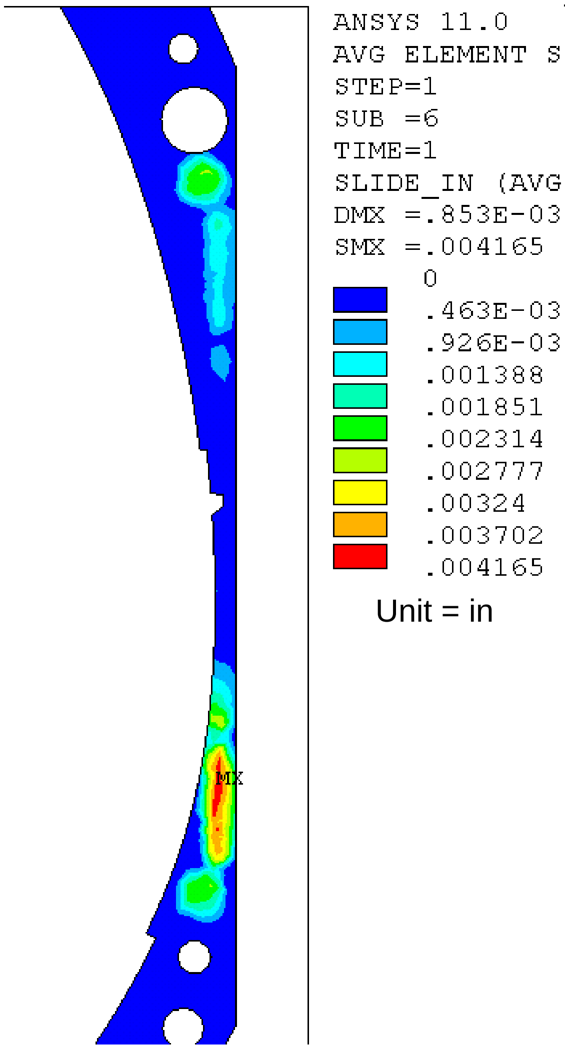


Shell Stresses appear as they did before in previous weld and bonded studies

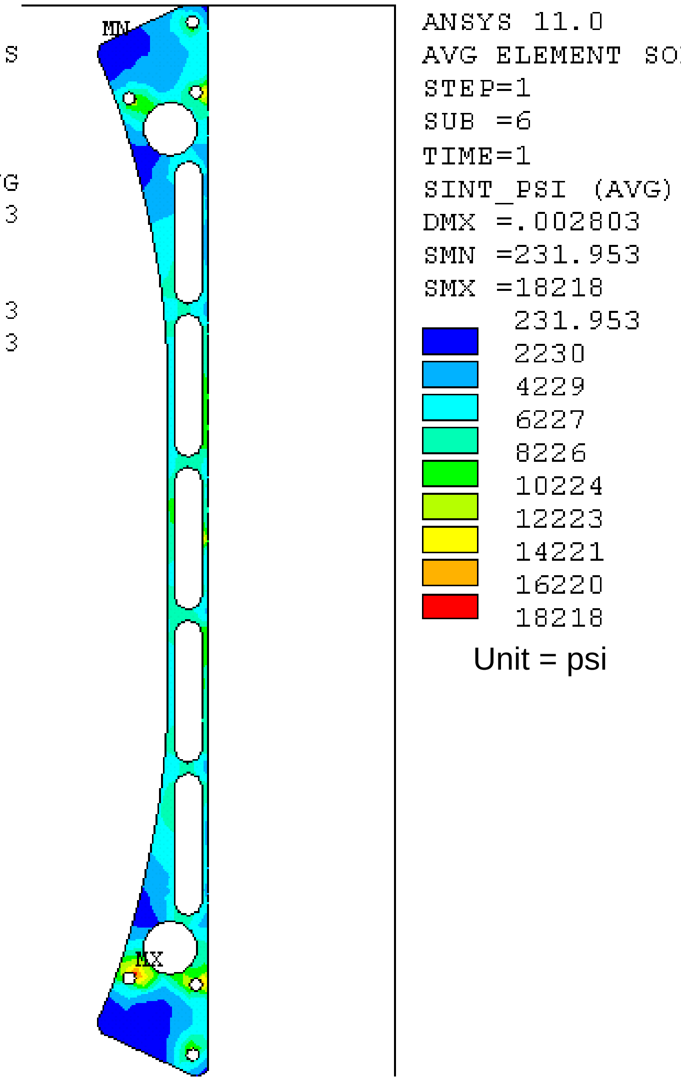


Stress Intensity of inner shim/studs/pucks

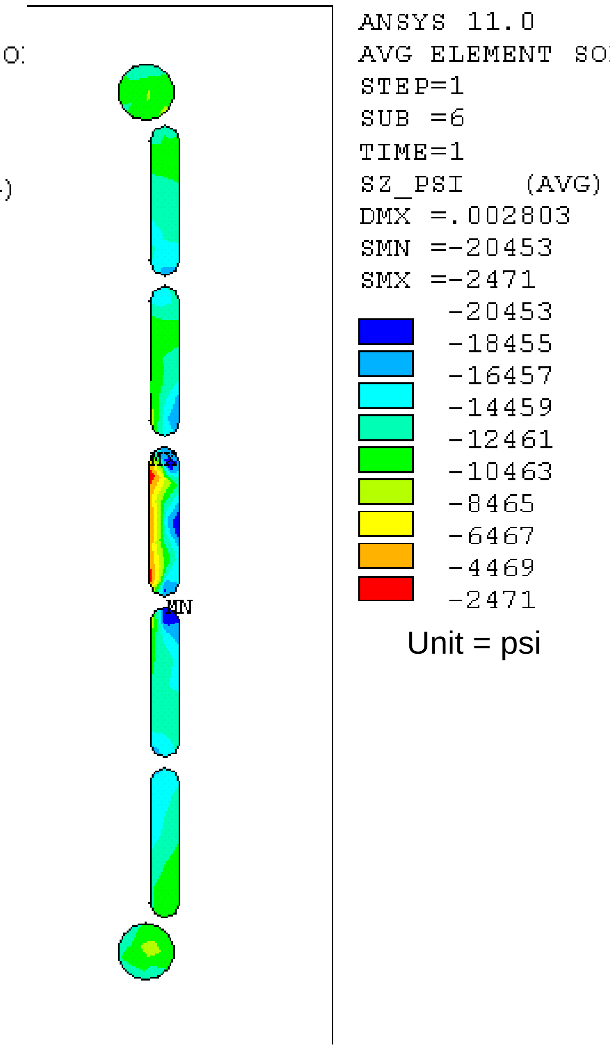
Case #2: Bonded outboard flange – mu = 0.4 under pucks



Contact Slip plot

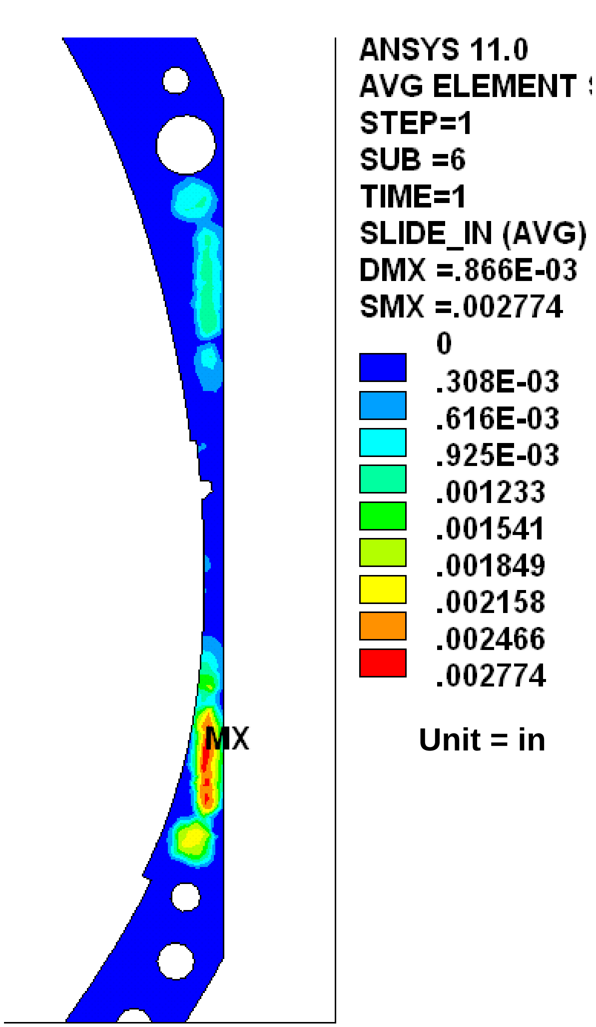


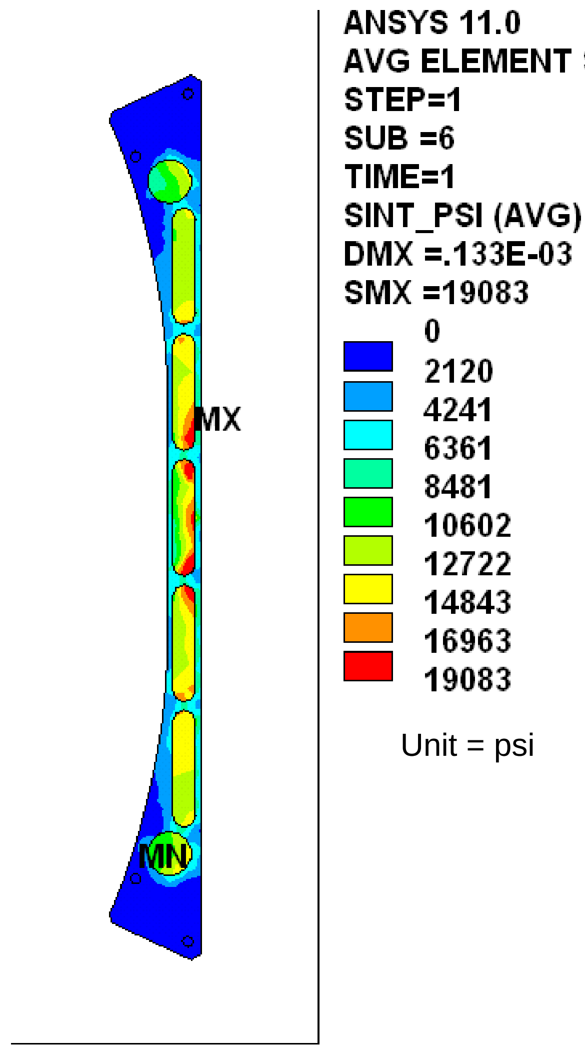
Stress Intensity of carrier



Puck Compressive Stress

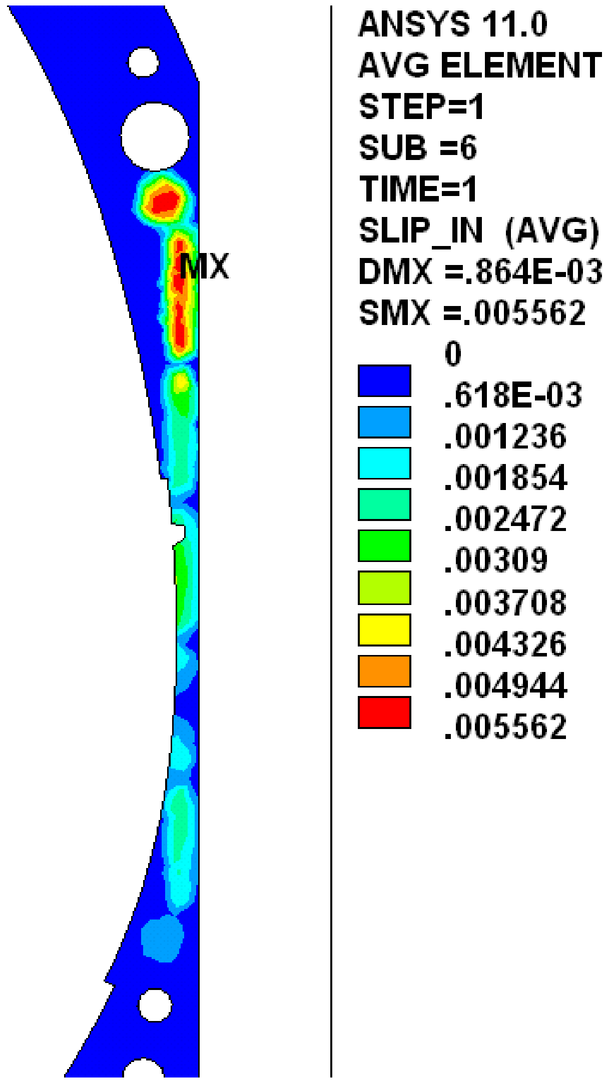
Case #3: No Studs- Bonded outboard flange – mu = 0.4 under pucks

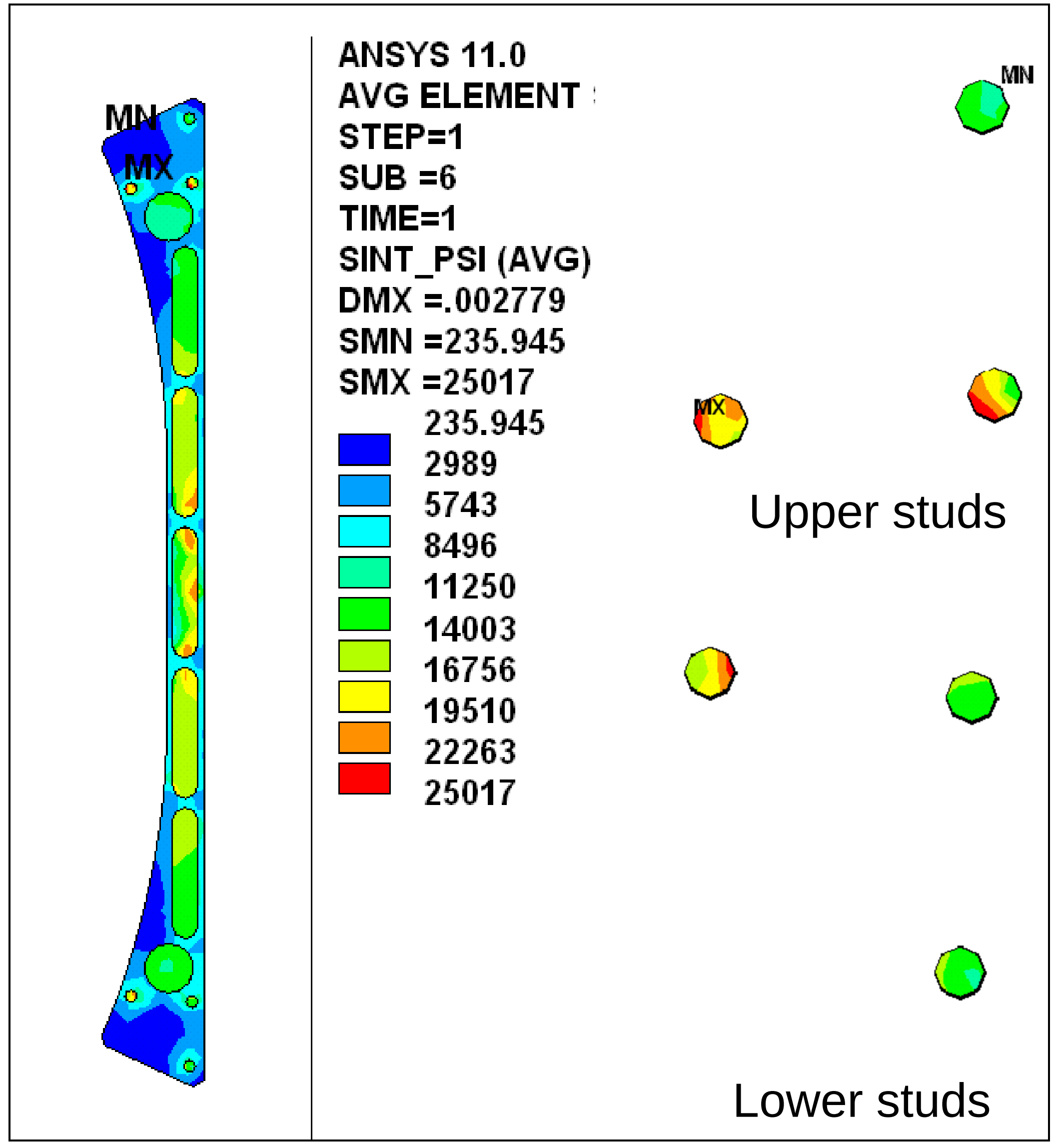




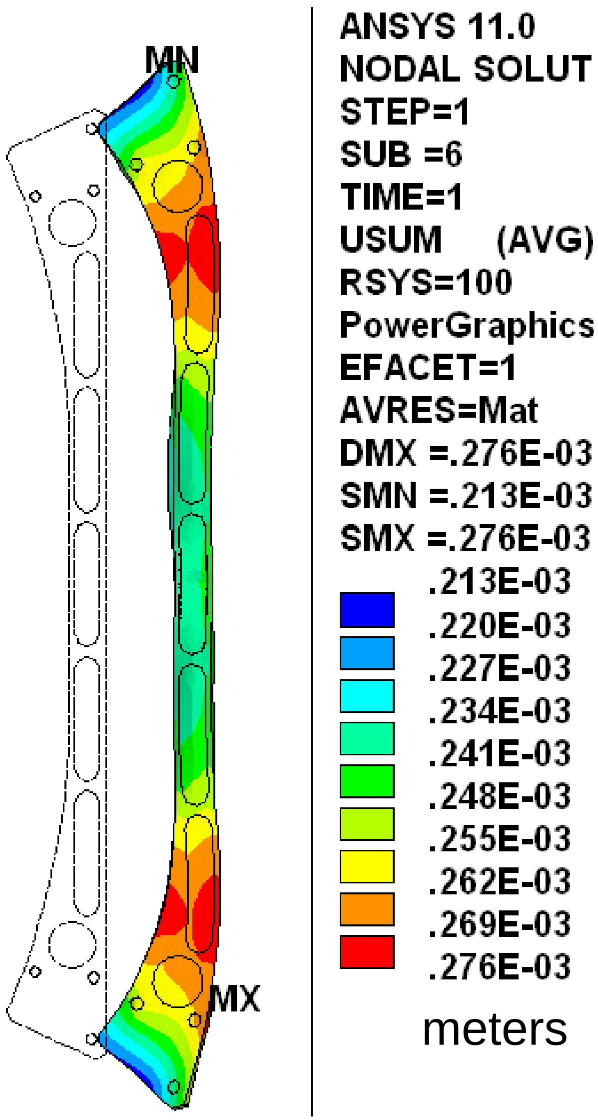
The center most pucks do not slip even if no studs are present

Case #4: Bonded outboard flange
mu = 0.0 under pucks (frictionless)

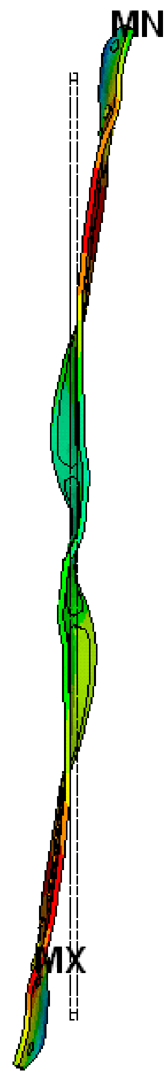




Case #4: Global deflection of inner shim



Front view



Side view

- Complete contact to the studs and carrier plate and frictionless pucks.
- Stress on the studs is due to the relative motion of the flange to the carrier plate.
- The flange is pulling the carrier plate vertically and is twisting. While the top half of the plate is being pushed inward and lower half is outward.
- Since the carrier plate will not see compression or shear and the inner most pucks remain stuck (case #3) the studs do not need to transit shear.
- The studs which are in reality not tight fitting will see minimal stress.

Summary table for inboard runs

Case	outboard configuration	# of studs	puck contact friction	peak puck sliding (in)	peak puck stress (ksi)	peak stud stress (ksi)
1	bolts	2 oblong	zero	0.0057	19.9	17.2
2	bonded	3	0.4	0.0042	20.4	30.8
3	bonded	0	0.4	0.0027*	19	n/a
4	bonded	3	zero	0.0056	21	25
5	bonded	2	0.4	0.0044	21.3	39.2

* the lower slippage is from the lack of stud/carrier stretching.

NCSX National Compact Stellarator Experiment

- 12 Added inboard bolts will reduce the motion of the inboard leg from .020” to less than .004”.
- All bolts remain “stuck” even when completely frictionless compression pucks are used on the inner legs
- The lower compression pucks will slip slightly (< 0.004”) and may ride up against the carrier plate. However, the middle compression pucks will remain “stuck” even if there are no studs present. Thus, the shim plate will be restrained during operation.
- Using the slotted holes instead of tight fitting circular holes around the studs allows eliminates the stress on the carrier plate and studs.
- Even with tight fitting studs, the stresses on the pins is within the allowable stress limit of 39.5 ksi.

Chit Resolution

E5 Concur - Action; P.J Fogarty

	B	C	D	E	F	G
1	**Rvw Date**	**#**	**Chit/Audit Finding [Originator]**	**Review Board Recommendation**	**Project Disposition**	**Responsibility**
2	8/7/2007	1	Include tooling design and fabrication/procurement in this scope of work. [Reiersen]	Concur - Action P.J Fogarty	Tooling design has been completed and demonstrated with prototypes. The final tooling will be procured and fabricated as part of station 6 prepartions.	
3	8/7/2007	2	Need to reconcile proposed design with project baseline (cost schedule and in sources) as well as the assembly sequence plan. Cost and schedule impacts possible in WBS 75 as well as WBS 14. [Reiersen]	Concur - Need to complete prior to OECM review. Action; Mike Cole	The assembly of the C to C shim configuration has been incorporated into the Assy sequence plan and was used to generate the current baseline schedule. The preparations for the OECM review are underway now and these updates are based on the proposed design.	
4	8/7/2007	3	Consider adding pins as a capture feature to guard against the risk of a "midplane" shim walking or falling out. [Reiersen]	Concur - Action; Mike Cole and Dave Williamson	The design addresses the risk of the pucks and carrier walking or falling out.	
5	8/7/2007	4	Ensure that you consider any issues associated with bringing all 3 120 degree field periods together. All mockups only use 1. [Viola]	Concur - Action; P.J Fogarty	A Pro E model/sterolithography of the three period assemblies and mechanisum for positioning the FPA will be fabricated to evaluate the assembly of the coils.	
6						

Risk

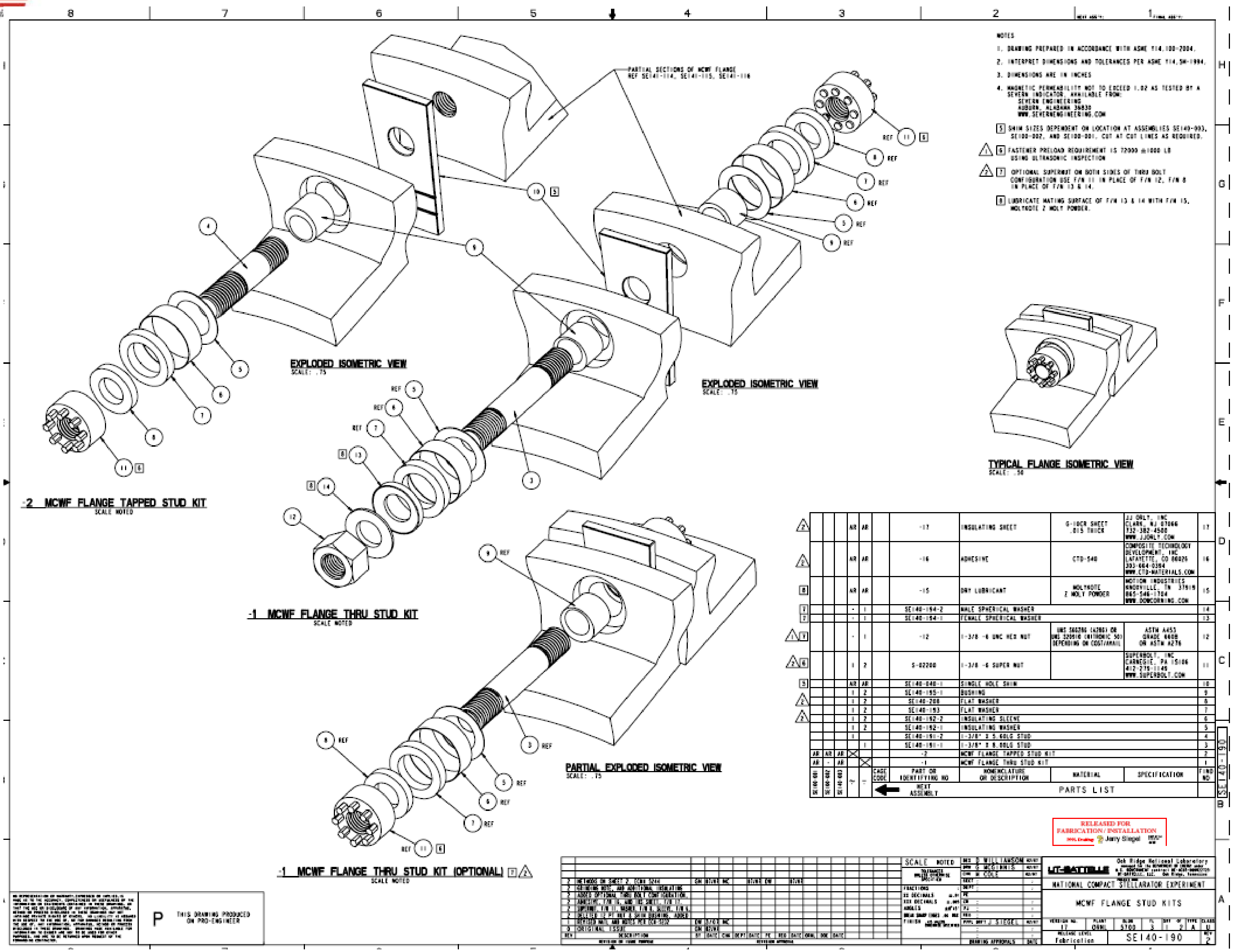
- Sizing shims will be challenging and will occur during tight schedule constraints. Any false starts will receive a lot of attention to solve problems quickly.
    - Suggest trial assembly with hardware to explore potential problems. We have time now if this activity could be done.
- Need to verify retainer and pucks will stay on flange during assembly (moving field periods). This could be a safety risk if individuals are under the machine.
    - Test could verify if this is/not an issue.
- Bolt preload could relax with time.
    - Strain gage sample of bolts to determine if bolt preload is changing with time. Retighten bolts/check periodically to verify preload is okay.

Conclusion

- Are the requirements defined? What is the proposed design?
  The design requirements have been defined from specs. Need to address Station 6 spec
- What is the status of mockup and access studies?
  Access for the bolting is feasible. Shims can be sized and assembled.
- Is the analysis consistent with proposed design?
  Analysis support the proposed concept
- Have prior design review chits been addressed?
  PDR Chits have been addressed – PDR was different then current concept
- Have all technical, cost, schedule, and safety risks been addressed?
  Access tooling is feasible. Schedule should be reviewed for consistency.

Backup Slides

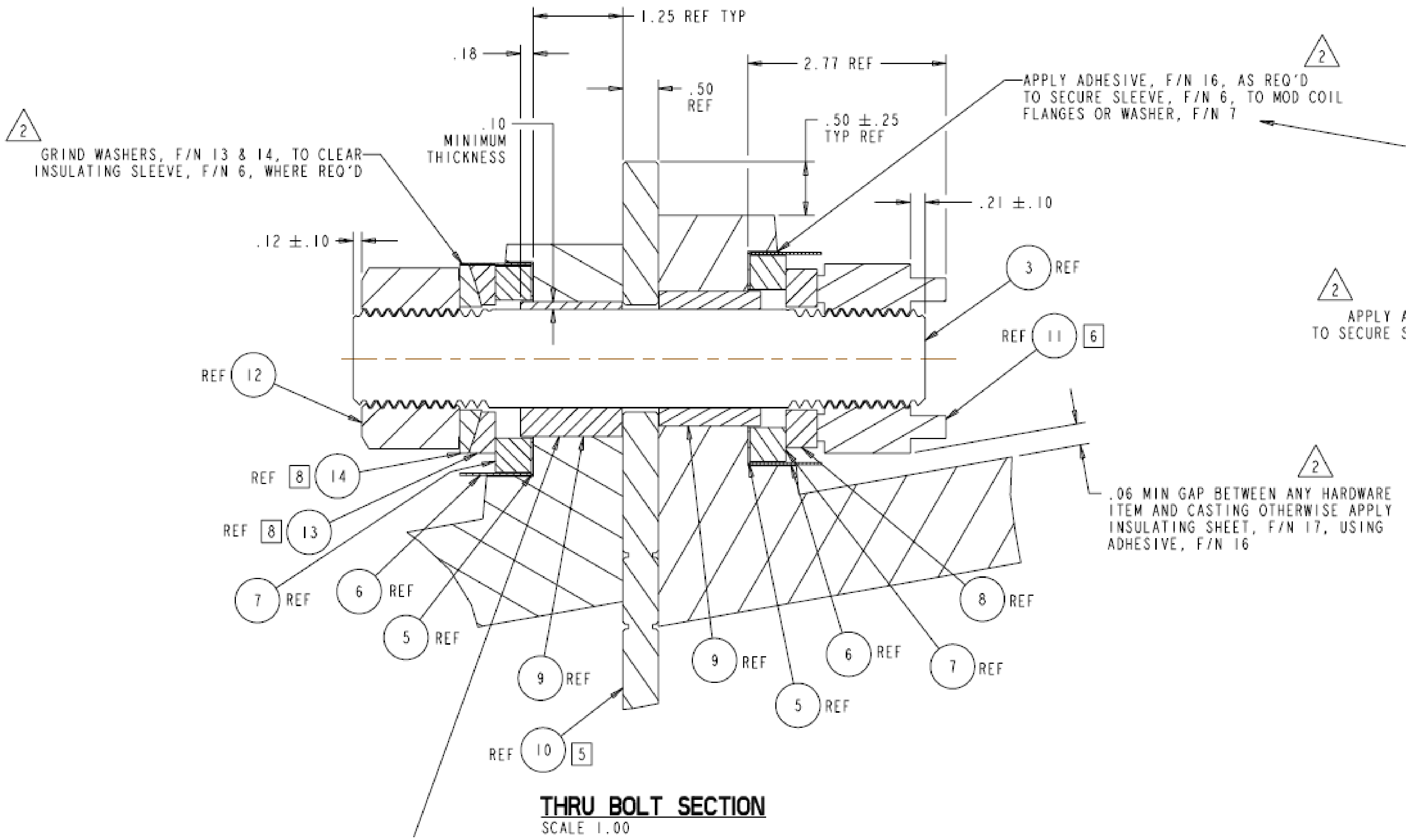
Bolted Joint Asm (SE140-190-R2)



PARTS LIST

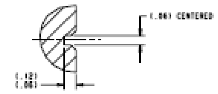
					CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
			AR	AR		-17	INSULATING SHEET	G-10CR SHEET .015 THICK	JJ ORLY, INC CLARK, NJ 07066 732-382-4500 WWW.JJORLY.COM	17
			AR	AR		-16	ADHESIVE	CTD-540	COMPOSITE TECHNOLOGY DEVELOPMENT, INC LAFAYETTE, CO 80026 303-664-0394 WWW.CTD-MATERIALS.COM	16
			AR	AR		-15	DRY LUBRICANT	MOLYKOTE Z MOLY POWDER	MOTION INDUSTRIES KNOXVILLE, TN 37919 865-546-1704 WWW.DOWCORNING.COM	15
			-	1		SE140-194-2	MALE SPHERICAL WASHER			14
			-	1		SE140-194-1	FEMALE SPHERICAL WASHER			13
			-	1		-12	1-3/8 -6 UNC HEX NUT	UNS S66286 (A286) OR UNS S20910 (NITRONIC 50) DEPENDING ON COST/AVAIL	ASTM A453 GRADE 660B OR ASTM A276	12
			1	2		S-02200	1-3/8 -6 SUPER NUT		SUPERBOLT, INC CARNEGIE, PA 15106 412-279-1149 WWW.SUPERBOLT.COM	11
			AR	AR		SE140-040-1	SINGLE HOLE SHIM			10
			1	2		SE140-195-1	BUSHING			9
			1	2		SE140-208	FLAT WASHER			8
			1	2		SE140-193	FLAT WASHER			7
			1	2		SE140-192-2	INSULATING SLEEVE			6
			1	2		SE140-192-1	INSULATING WASHER			5
			1			SE140-191-2	1-3/8" X 5.60LG STUD			4
				1		SE140-191-1	1-3/8" X 8.00LG STUD			3
AR	AR	AR	X			-2	MCWF FLANGE TAPPED STUD KIT			2
AR	-	AR		X		-1	MCWF FLANGE THRU STUD KIT			1
SE100-001	SE100-002	SE140-003	-2	-1		NEXT ASSEMBLY				

Bolted Joint Asm (SE140-190-R2)



Shim (SE140-040-R0)

NCSX National Compact Stellarator Experiment

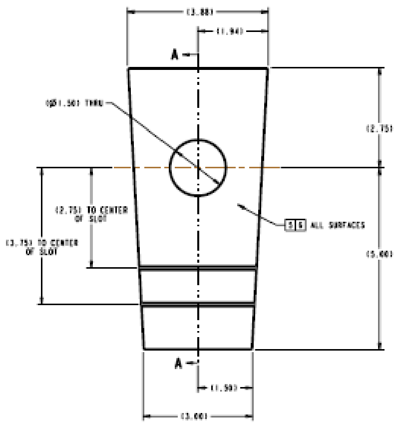


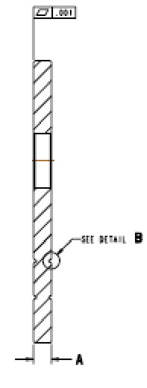
DETAIL B
SCALE 4.00

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. [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. [5] ALUMINA COATING PER SPECIFICATION NCSX-CSPEC-142-06-00.
6. [6] SURFACE FINISH AFTER COATING 150-500.
   SURFACE FINISH ON NON-COATED PART 125 OR LESS UNLESS OTHERWISE SPECIFIED BY COATING SUPPLIER.

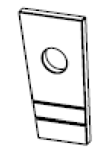




SECTION A-A

TOTAL 214

QTY REQ'D	DIM A FINISHED SIZE ALUMINA COATED THICKNESS PER SIDE .025 +.003 / -.002	FINISHED SIZE MIN	FINISHED SIZE MAX	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

-1 SHINGLE HOLE SHIM
SCALE 1.00

NOTE: DIMENSIONS SHOWN ON THIS SHEET APPLY AFTER COATING
SEE SHEET 2 FOR NON-COATED PART

RELEASED FOR FABRICATION / INSTALLATION
Jerry Siegel

SE140-040-001	SE140-040-002	SE140-040-003	CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
AR	AR	AR		SEE CHART	SINGLE HOLE SHIM	316 SST [4] PLASMA ALUMINA COATED [5]	ASTM A240	1

NEXT ASSEMBLY — PARTS LIST

P THIS DRAWING PRODUCED ON PRO-ENGINEER

0 ORIGINAL ISSUE

SCALE NOTED

DES D. WILLIAMSON
DRN G. MCGINNIS
CHK W. COLE
PPPL DEPT J. SIEGEL
DRAWING APPROVALS

UT-BATTELLE
Oak Ridge National Laboratory

NATIONAL COMPACT STELLARATOR EXPERIMENT

SINGLE HOLE SHIM PLATE

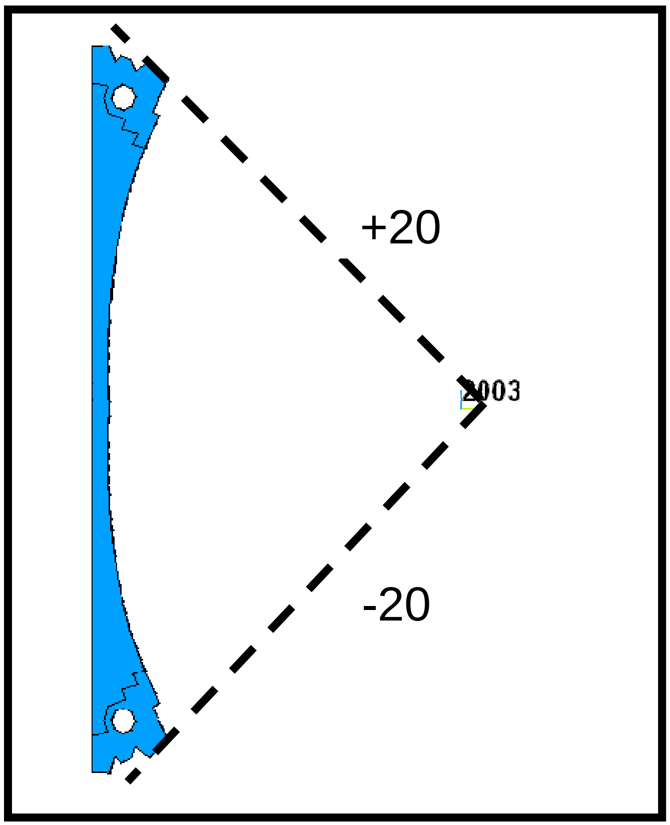
VERSION NO. 18 | PLANT ORNL | BLDG 5700 | SHT 1 OF 2 | TYPE 3 | CLASS U
RELEASE LEVEL Fabrication

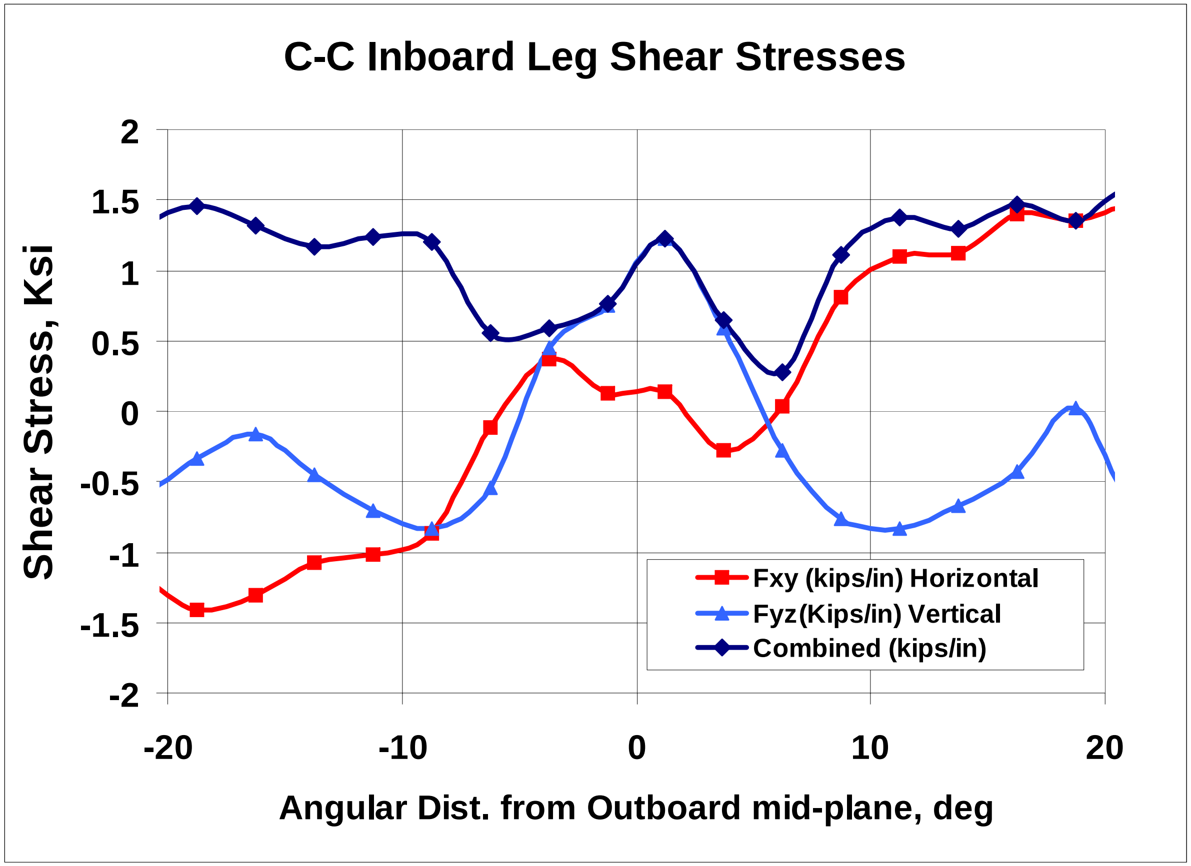
SE140-040 REV 0

Extra backup slides for analysis

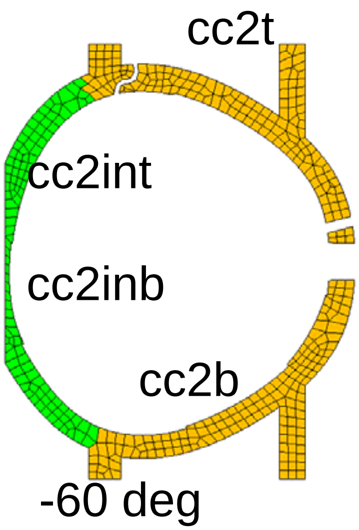
Oblong studs from pervious runs
are replaced by round studs.

Bonded shear stress-detail

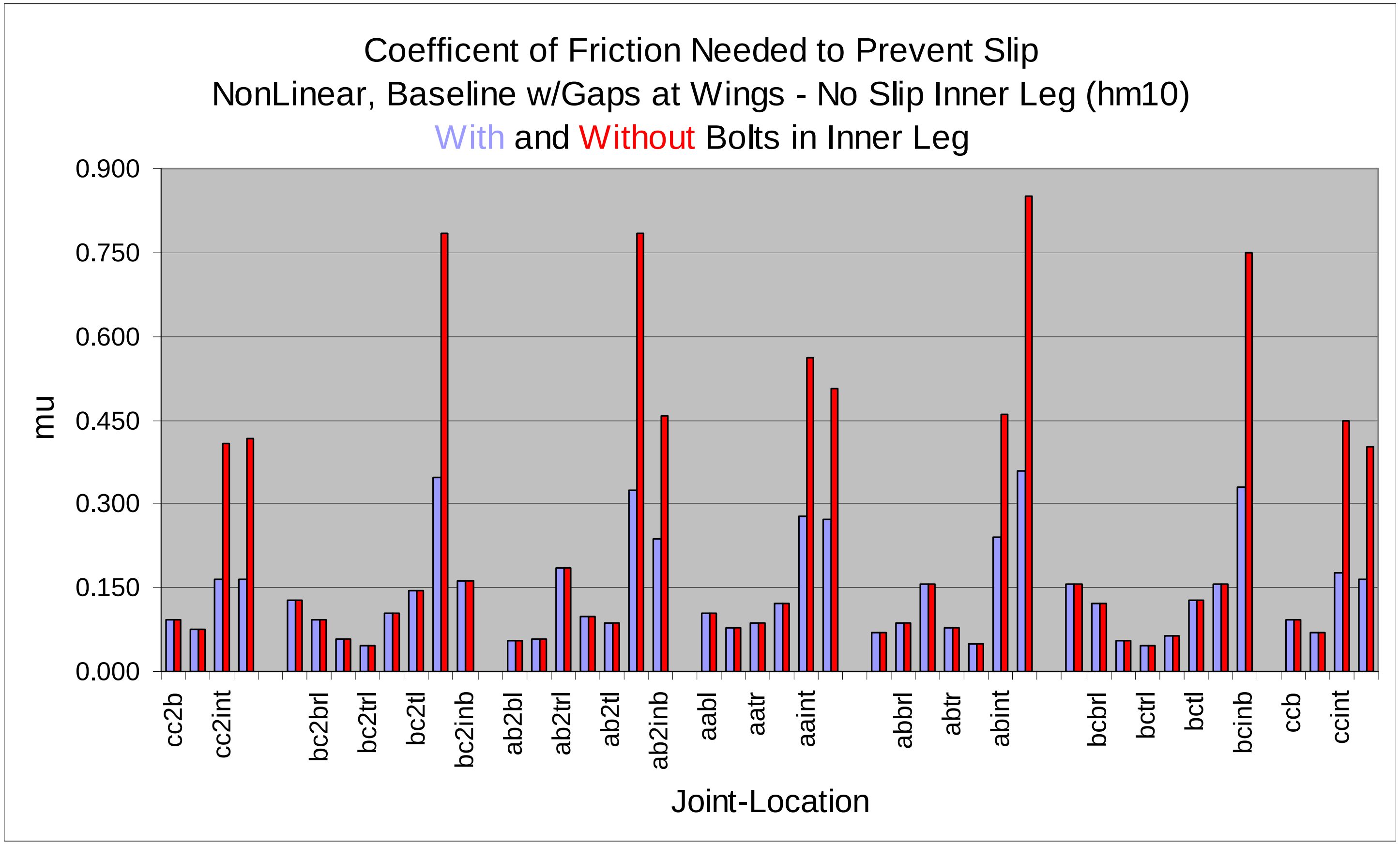




Previous CC work for coefficient of fric

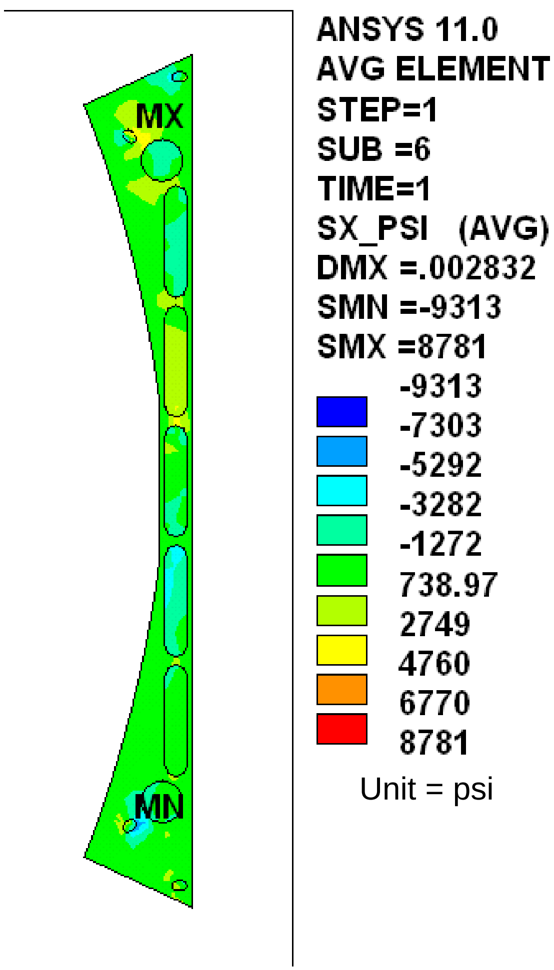


Green Regions (*in) unbolted

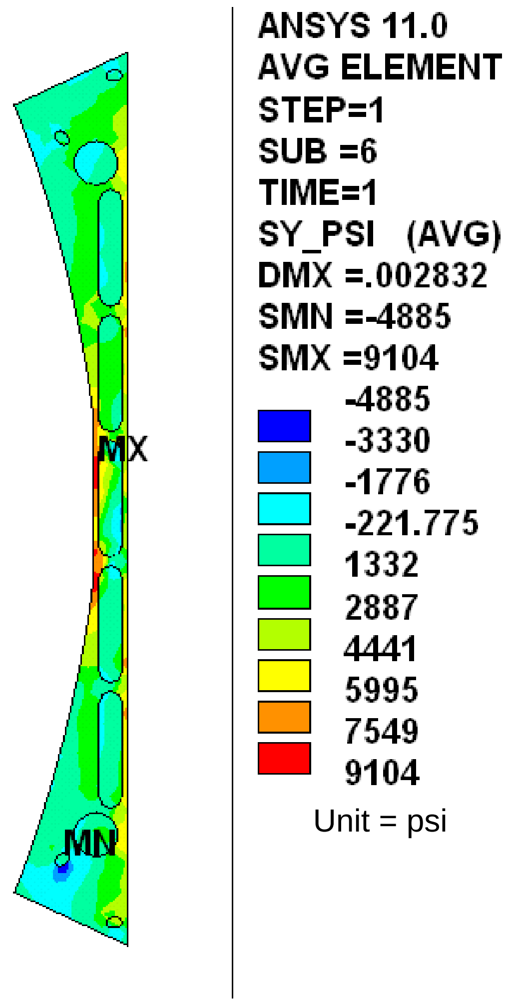


Case #2: Bonded outboard flange – mu = 0.4 under pucks- Directional Stresses (PSI)

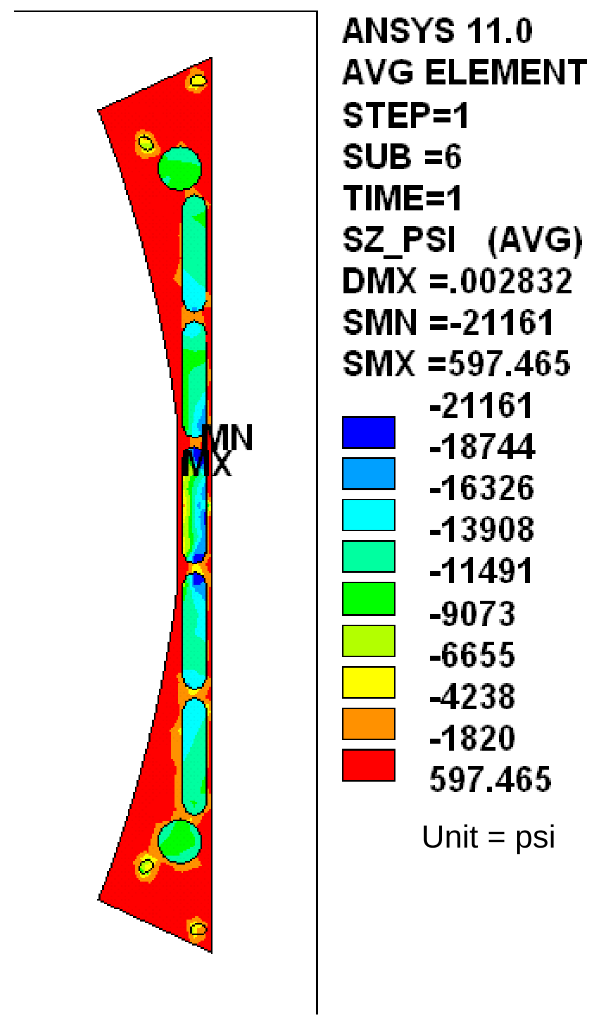
Frictionless pucks



Horizontal Stress

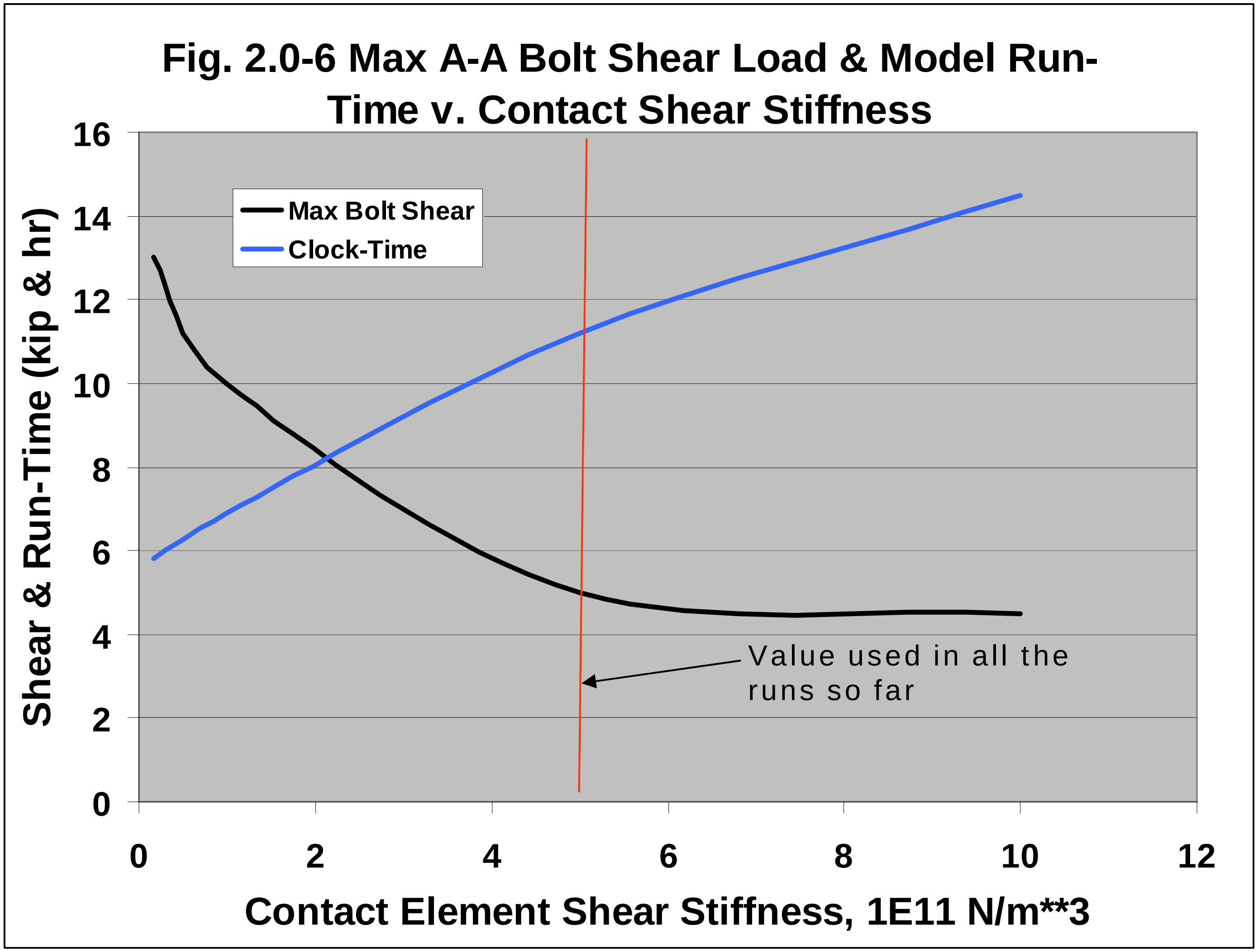


Vertical Stress



Normal Stress

We Picked -5e11 N/m^3 to use on all our runs



This value may be too small especially in areas of high shear and slippage (like the inner leg of CC)

Inner Leg Bolts Only