NCSX National Compact Stellarator Experiment

Engineering/Design of the Welded Inner Leg Interfaces for the NCSX Modular Coils A-A, A-B, B-C PDR

Presented by
T Brown, M Cole, K Freudenberg, D Williamson, and M Viola

October 18, 2007

Review Charge

- Are the requirements defined? What is the proposed design?
- What is the status of welding trials?
- Is the analysis consistent with proposed design?
- What is the plan to complete final design?
- Have prior design review chits been addressed?
- Have all technical, cost, schedule, and safety risks been addressed?

Scope

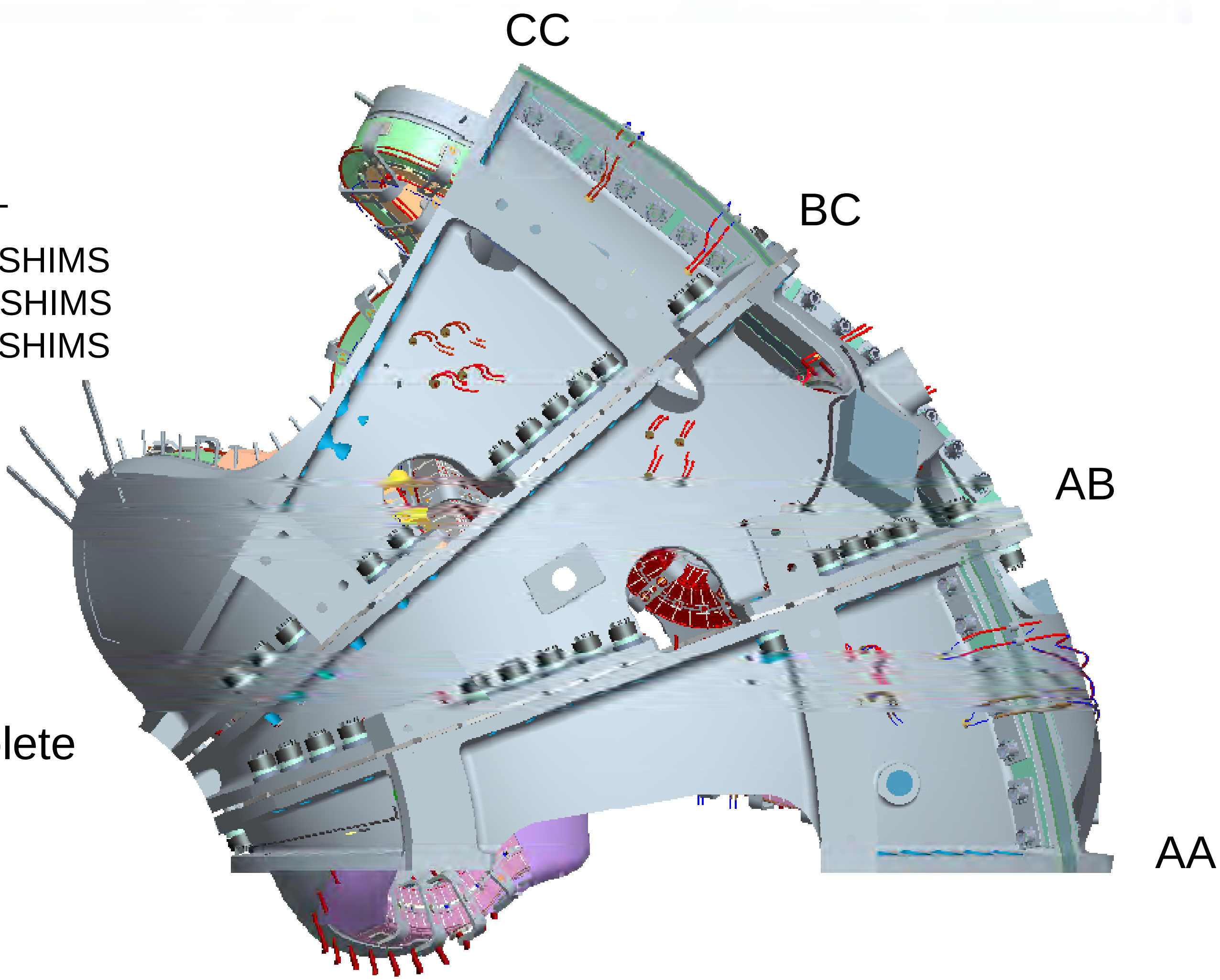
- This review-
  AA/AB/BC interface:

  SE140-046, SHIM LAYOUT
  SE140-052, AB INBOARD SHIMS
  SE140-053, BC INBOARD SHIMS
  SE140-054, AA INBOARD SHIMS

- Upcoming reviews:

  AA/AB/BC Interface
  FDR 11/22/07

  CC Interface
  PDR 8/7/07 Complete
  FDR 1/7/08



Requirements

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

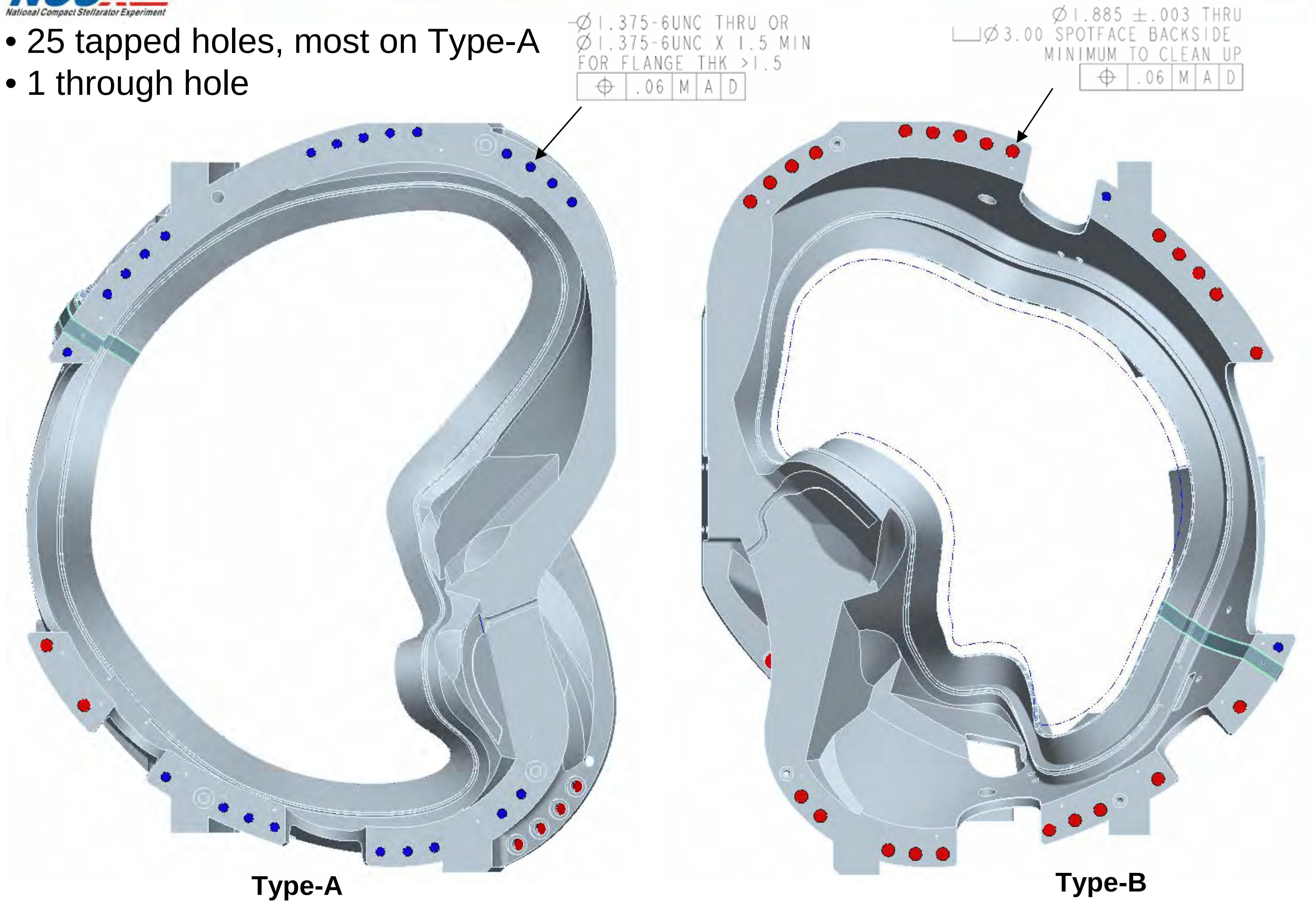
- Carry compressive and shear loads

Assembly

- Position the coil fiducials to +/- .020 inch at the half period assembly

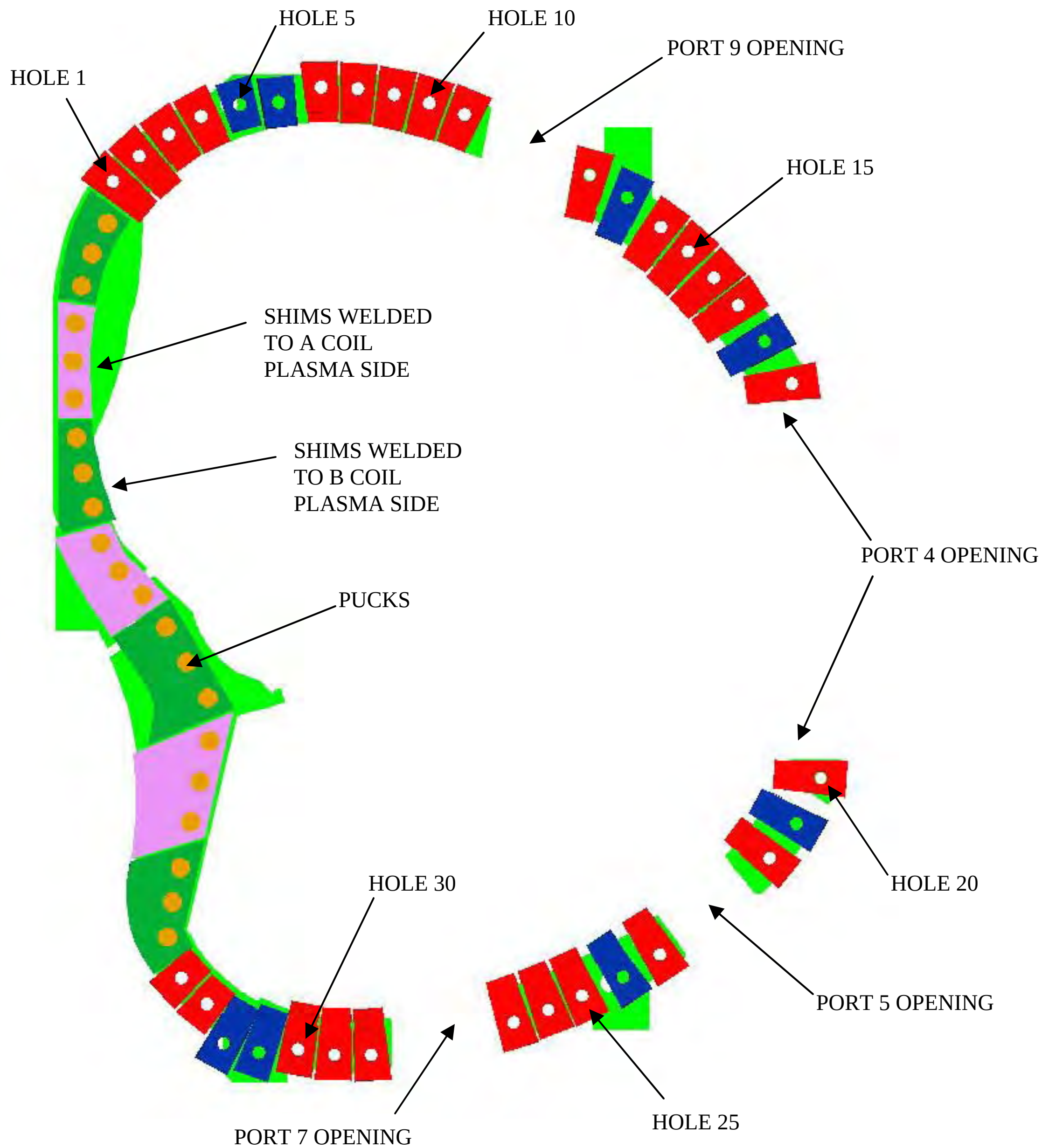
Interface A-B

- 25 tapped holes, most on Type-A
- 1 through hole

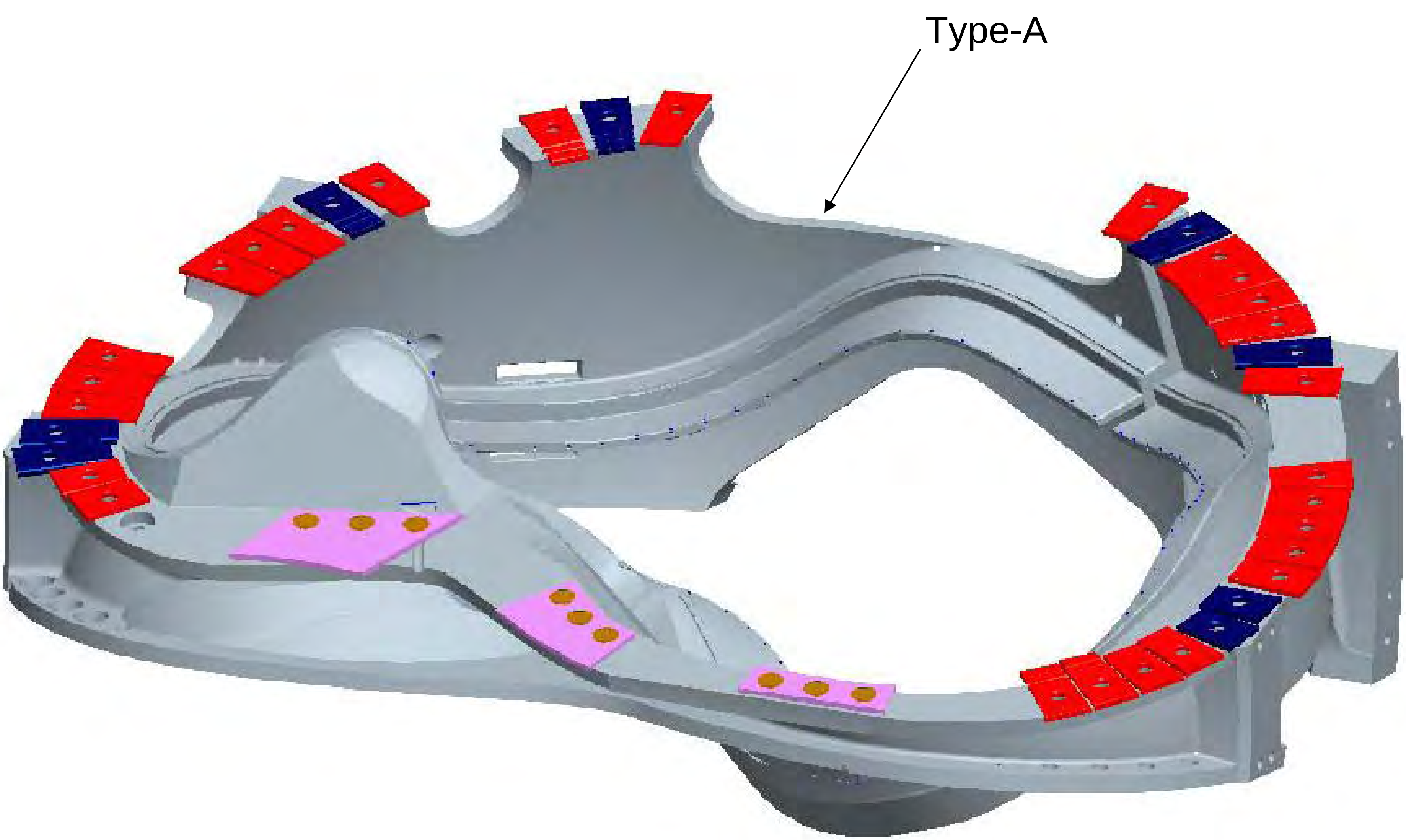


A-B FLANGE

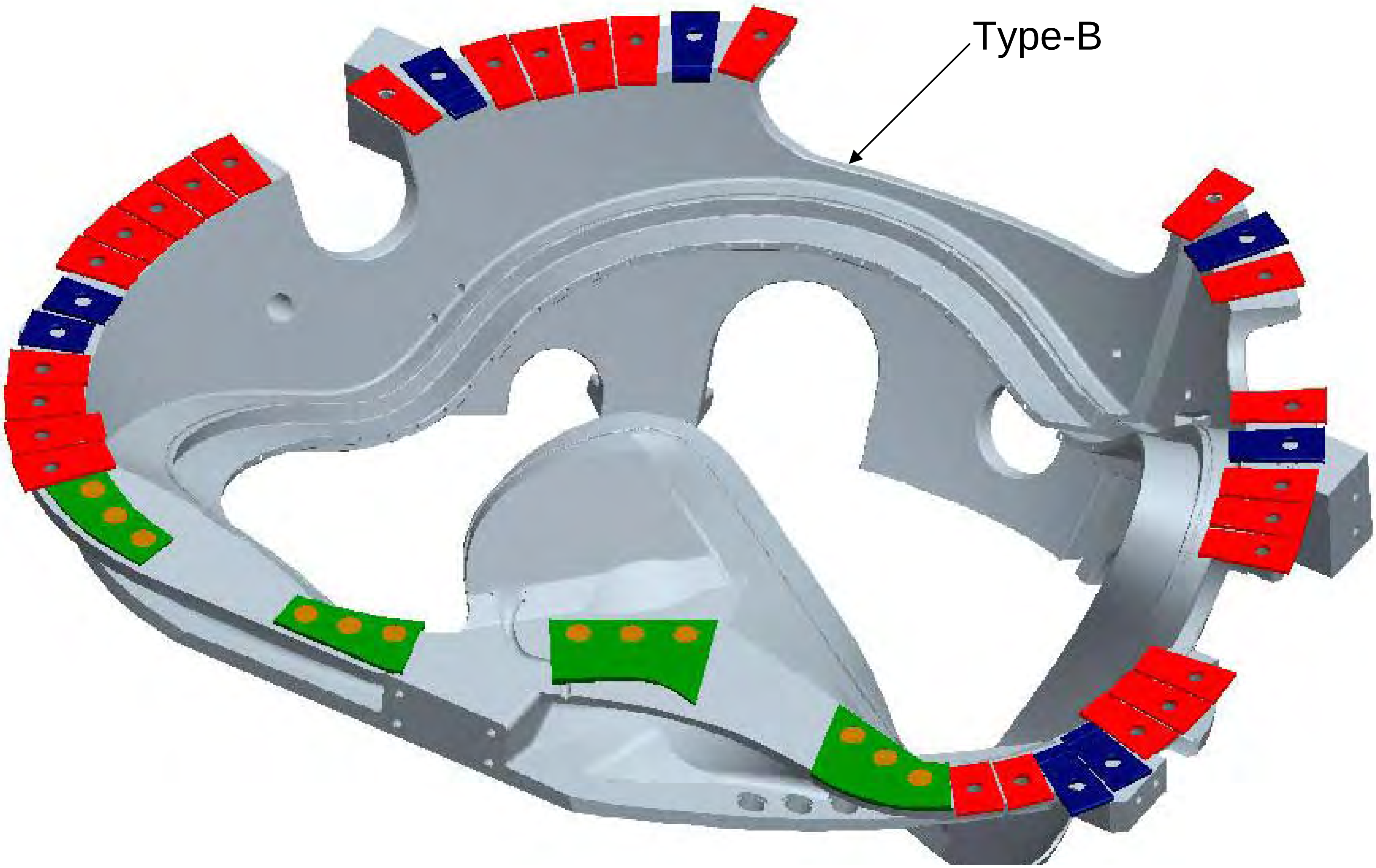
AB Hole #	Shim Length Hole to Bottom	No Bolt Shim
1	5.00	
2	5.00	
3	3.75	
4	3.75	
5		2.75
6		2.75
7	3.75	
8	3.75	
9	3.75	
10	3.75	
11	3.75	
12	5.00	
13		5.00
14	5.00	
15	5.00	
16	5.00	
17	5.00	
18		5.00
19	5.00	
20	5.00	
21		5.00
22	5.00	
23	5.00	
24		5.00
25	5.00	
26	5.00	
27	5.00	
28	5.00	
29	5.00	
30	5.00	
31		5.00
32		5.00
33	2.75	
34	2.75	

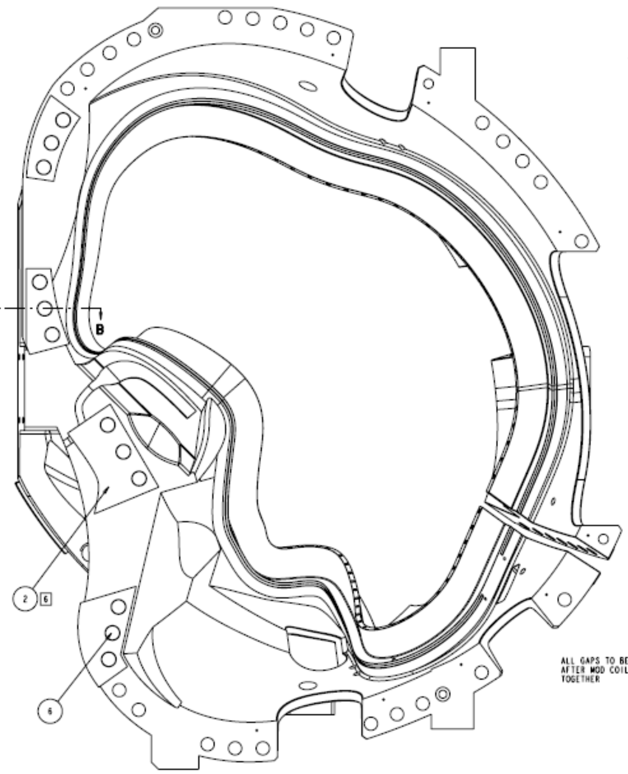


AB Inboard Welded Shims

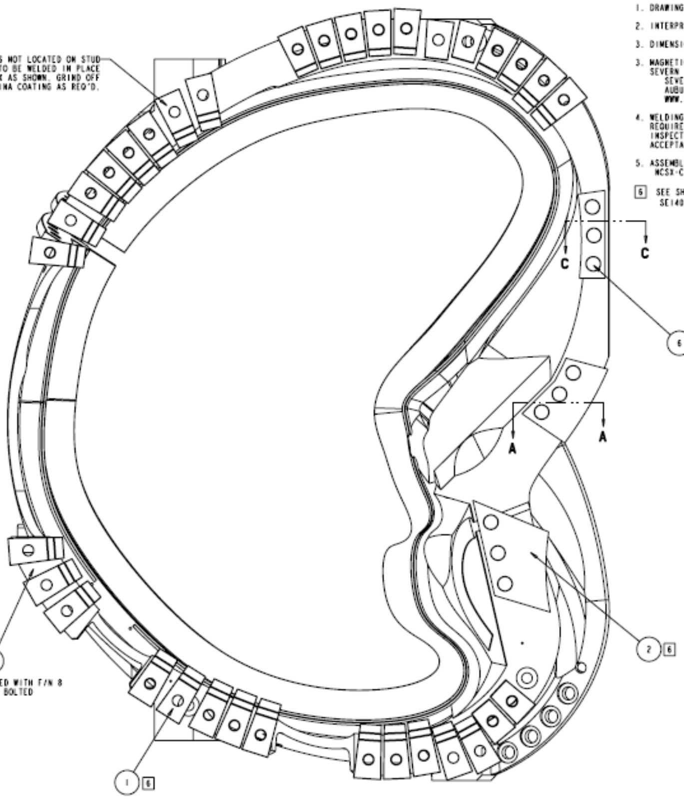


AB Inboard Welded Shims





A-B SHIMS LOOKING AT THE B COIL FLANGE
(A COIL REMOVED)



A-B SHIMS LOOKING AT THE A COIL FLANGE
(B COIL REMOVED)

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
3. MAGNETIC PERMEABILITY NOT TO EXCEED 1.02 AS TESTED BY A SEVERN INDICATOR. AVAILABLE FROM:
   SEVERN ENGINEERING
   AUBURN, ALABAMA 36830
   WWW.SEVERNENGINEERING.COM
4. WELDING SHALL BE PERFORMED IN ACCORDANCE WITH THE REQUIREMENTS OF PPPL PROCEDURE ENG-037. VISUAL WELD INSPECTION SHALL BE PERFORMED IN ACCORDANCE WITH THE ACCEPTANCE CRITERIA OF AWS D1.1 SECTION 6.
5. ASSEMBLE PER THIS DRAWING AND SPECIFICATION NCSX-CSPEC-185-01.

[6] SEE SHIM DRAWINGS SE140-040, SE140-052, SE140-053, SE140-054 AND SE140-055 FOR ADDITIONAL INFORMATION.

MODULAR COIL SHIM PLATE LAYOUT
SCALE .18

NOTE: MOD COILS SHOW AS PART ONLY FOR CLARITY
SHIMS TO BE INSTALLED ON MOD COIL ASSEMBLIES

AR	AR	AR		-9	FILLER	GREAT STUFF		9
AR				-8	PIPE 1-1/2 SCH 80 X 1-3/8" LG	316L SST	ASTM A312	8
AR				-7	STUD Ø1/2 X 3/8" LG		ASTM A276	7
	AR	AR		-6	PUCK			6
AR				SE140-055	C-C INBOARD SHIMS			5
	AR			SE140-054	A-A INBOARD SHIMS			4
		AR		SE140-053	B-C INBOARD SHIMS			3
		AR		SE140-052	A-B INBOARD SHIMS			2
AR	AR	AR		SE140-040	SINGLE HOLE SHIM			1
SE100-001	SE100-003	SE140-003	CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
			← NEXT ASSEMBLY		PARTS LIST			

SE140-046

WELDING ENGINEER
APPROVED L. DUDEK DATE: 09/07

PRELIMINARY
10-18-2007

NO REPRESENTATION OR WARRANTY, EXPRESSED OR IMPLIED, IS MADE AS TO THE ACCURACY, COMPLETENESS OR USEFULNESS OF THE INFORMATION OR STATEMENTS CONTAINED IN THESE DRAWINGS, OR THAT THE USE OF OR DISCLOSURE OF ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THESE DRAWINGS MAY NOT INFRINGE PRIVATE RIGHTS OF OTHERS. NO LIABILITY IS ASSUMED WITH RESPECT TO THE USE OF, OR FOR DAMAGES RESULTING FROM THE USE OF, ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THESE DRAWINGS. DRAWINGS MADE AVAILABLE FOR INFORMATION TO BIDDER ARE NOT TO BE USED FOR OTHER PURPOSES, AND ARE TO BE RETURNED UPON REQUEST OF THE PURCHASING CONTRACTOR.

P THIS DRAWING PRODUCED ON PRO-ENGINEER

REV	DESCRIPTION	BY	DATE	CHK	DEPT	DATE	PE	RED	DATE	ORNL	DOE	DATE
0	ORIGINAL ISSUE	GM	09/07									
REVISION OR ISSUE PURPOSE		REVISION APPROVAL										

SCALE NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS :
XX DECIMALS ±.01
XXX DECIMALS ±.005
ANGLES ±0° 15'
BREAK SHARP EDGES .06 MAX
FINISH 125 UNLESS OTHERWISE SPECIFIED

DRAWING APPROVALS		DATE
DES	D WILLIAMSON	09/2007
DRN	G MCGINNIS	09/2007
CHK	M COLE	09/2007
SECT	:	:
DEPT	:	:
PE	:	:
CR	:	:
PJ	:	:
RED	:	:
PPPL ORT	J SIEGEL	09/2007

UT-BATTELLE
Oak Ridge National Laboratory
managed for the DEPARTMENT OF ENERGY under U.S. GOVERNMENT contract DE-AC05-00OR22725
UT-BATTELLE, LLC. Oak Ridge, Tennessee

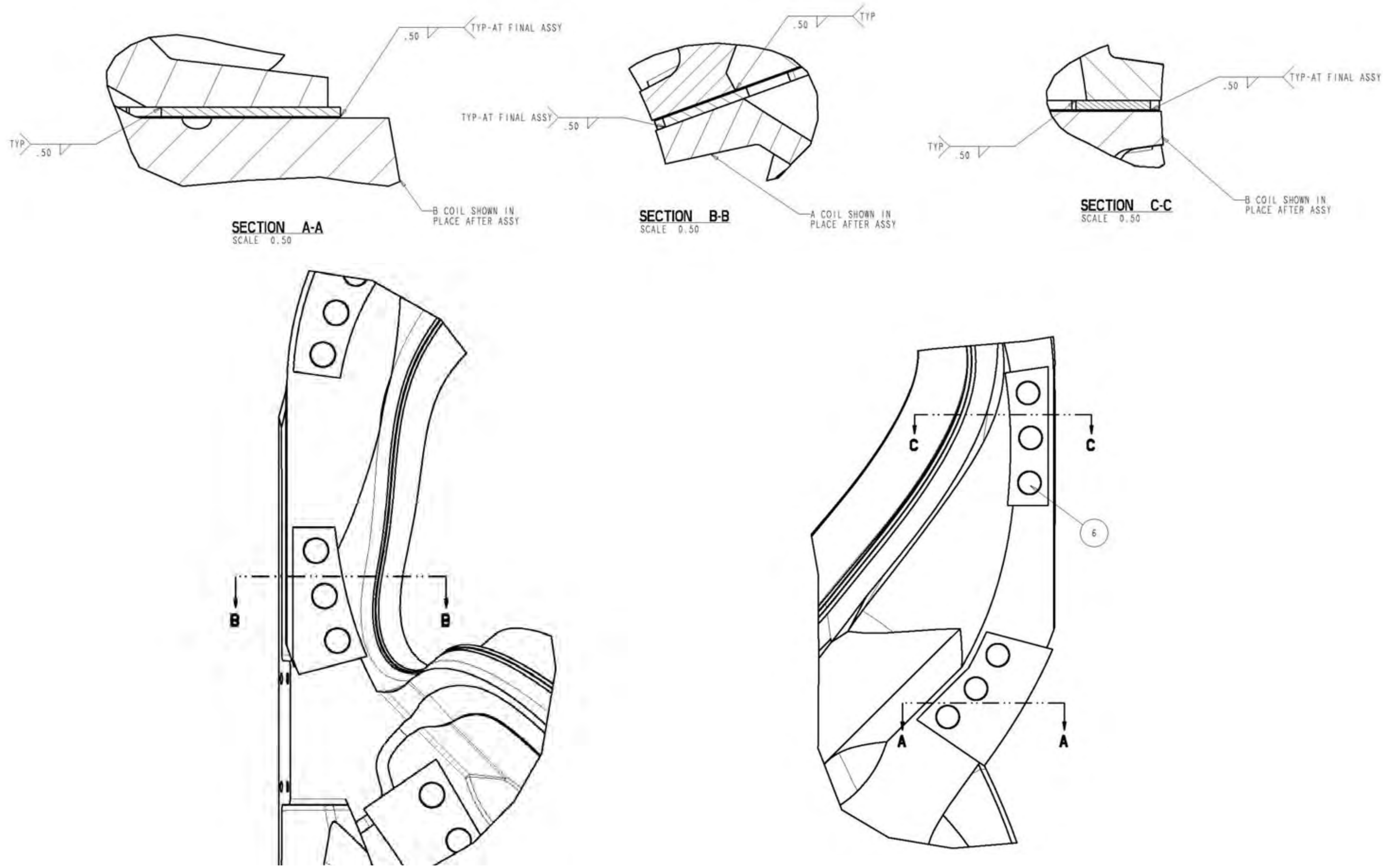
PROJECT NAME
NATIONAL COMPACT STELLARATOR EXPERIMENT

MODULAR COIL SHIM PLATE LAYOUT

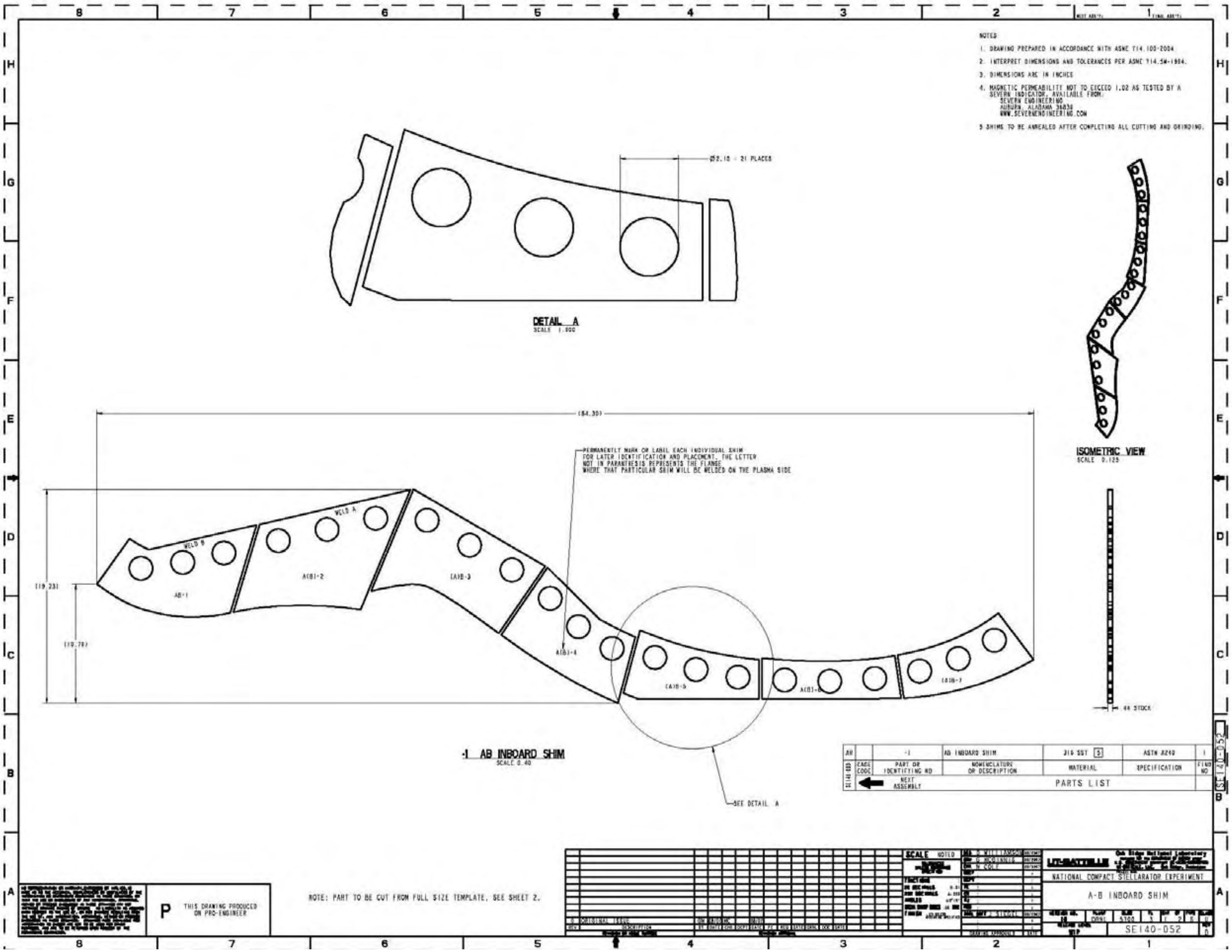
VERSION NO.	PLANT	BLDG	FL	SHT	OF	TYPE	CLASS
11+	ORNL	5700	3	1	4	S	U

RELEASE LEVEL WIP
SE140-046
REV 0

AB Inboard Welded Shims

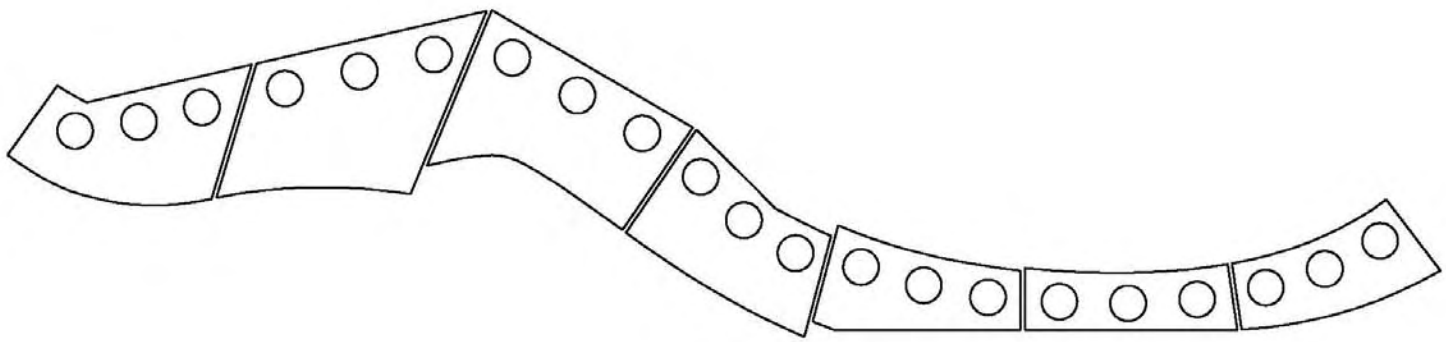


AB Inboard Welded Shims (SE140-052)

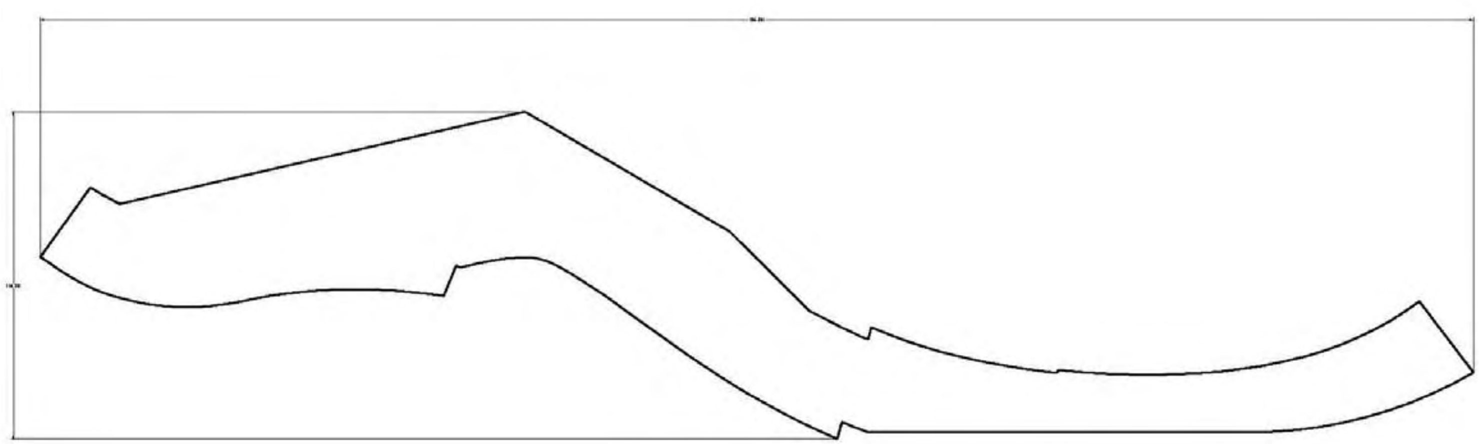


AB Inboard Welded Shims (SE140-052)

NCSX National Compact Stellarator Experiment



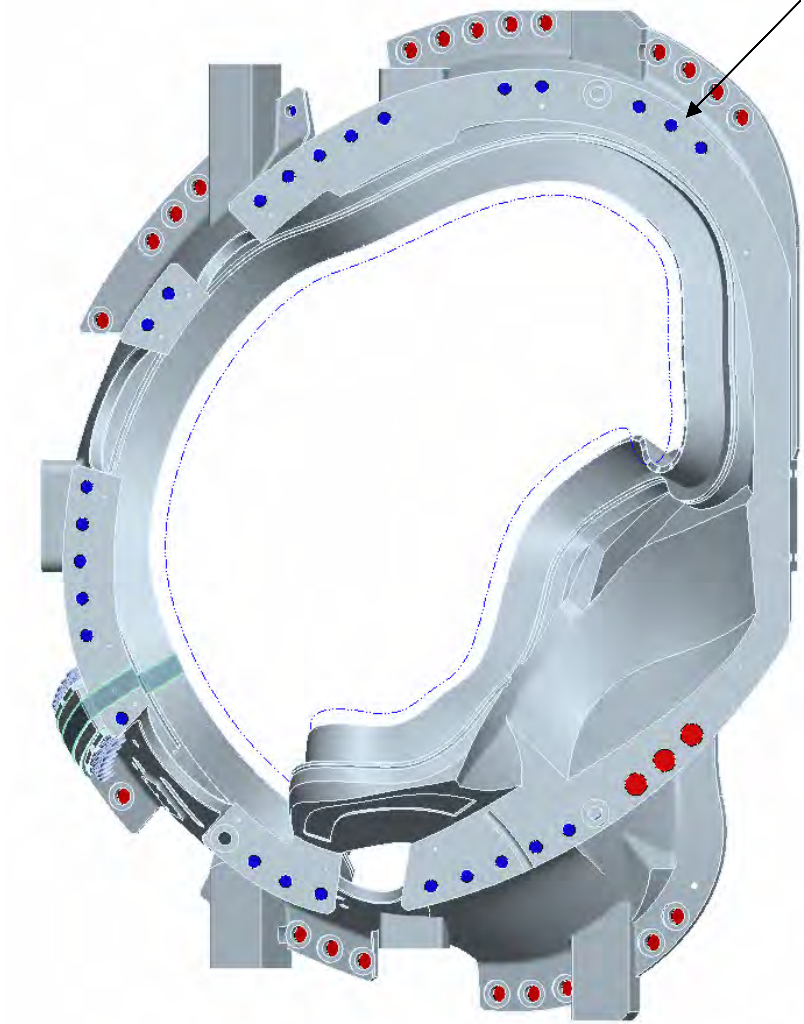
FULL SIZE TEMPLATE - WITH INDIVIDUAL CUT LINES AND PUCK HOLE LOCATIONS
SCALE 1 : 1



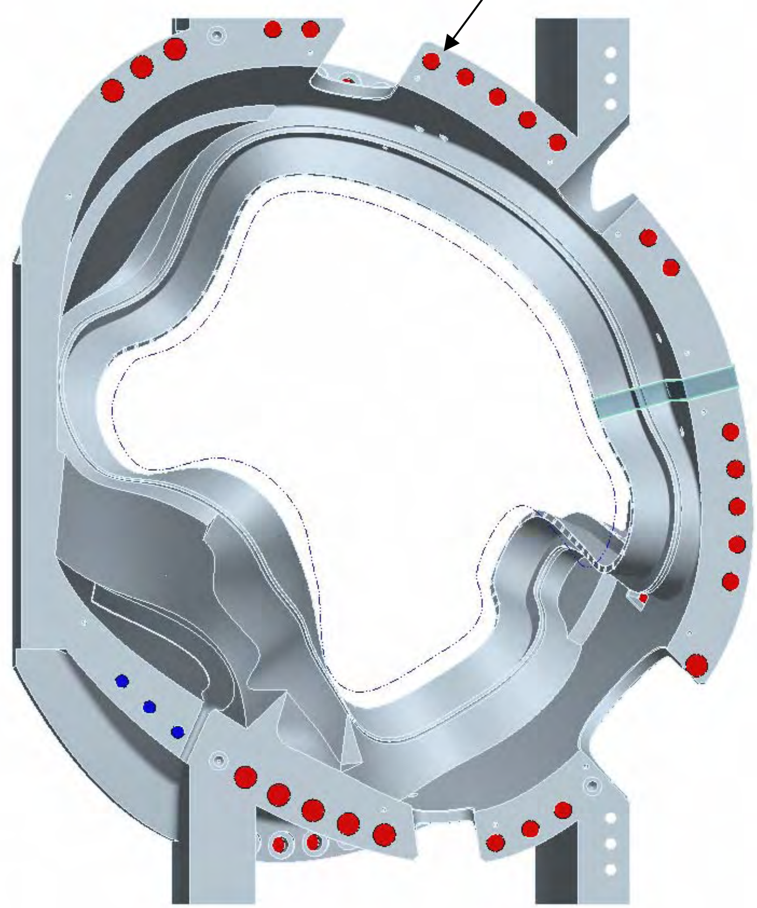
FULL SIZE TEMPLATE - CHECK REF DIMS SHOWN FOR PROPER SCALE
SCALE 1 : 1

Interface B-C

• 29 tapped holes, most on Type-B



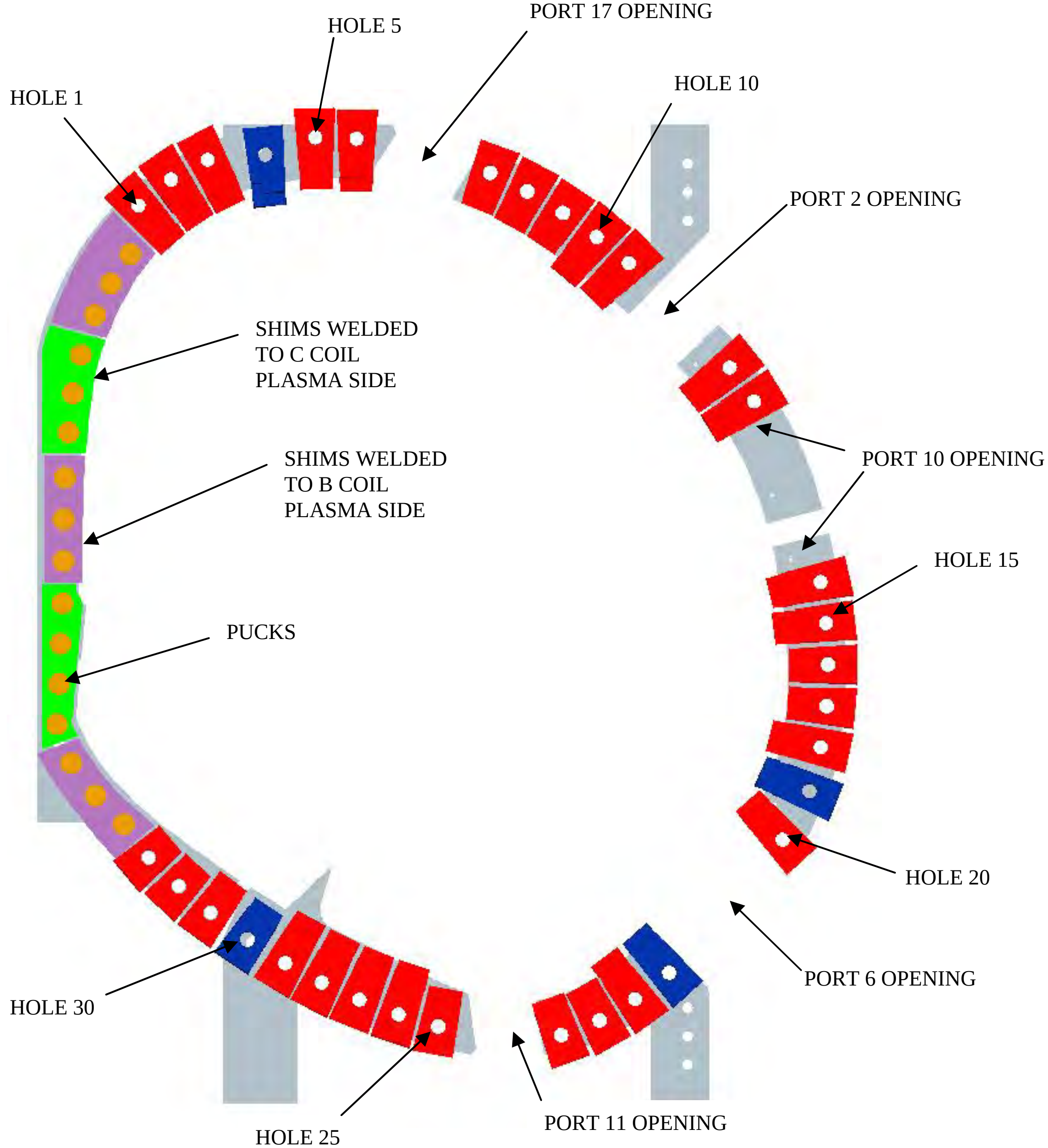
Type-B



Type-C

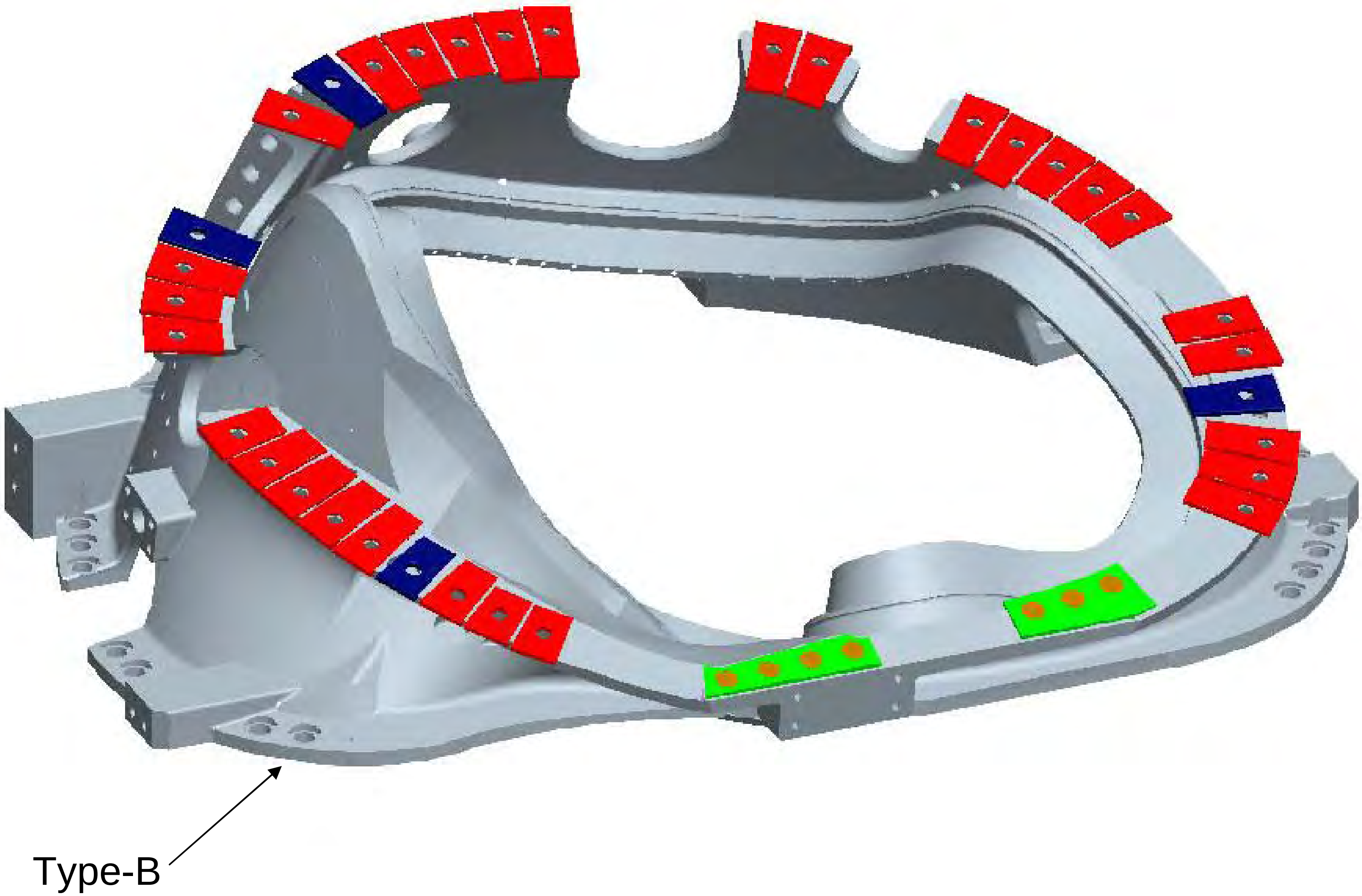
B-C FLANGE

BC Hole #	Shim Length Hole to Bottom	No Bolt Shim
1	5.00	
2	5.00	
3	5.00	
4		5.00
5	5.00	
6	5.00	
7	3.75	
8	3.75	
9	3.75	
10	5.00	
11	5.00	
12	5.00	
13	5.00	
14	5.00	
15	5.00	
16	3.75	
17	3.75	
18	5.00	
19		5.00
20	5.00	
21		5.00
22	5.00	
23	3.75	
24	3.75	
25	3.75	
26	5.00	
27	5.00	
28	5.00	
29	5.00	
30		3.75
31	3.75	
32	2.75	
33	2.75	

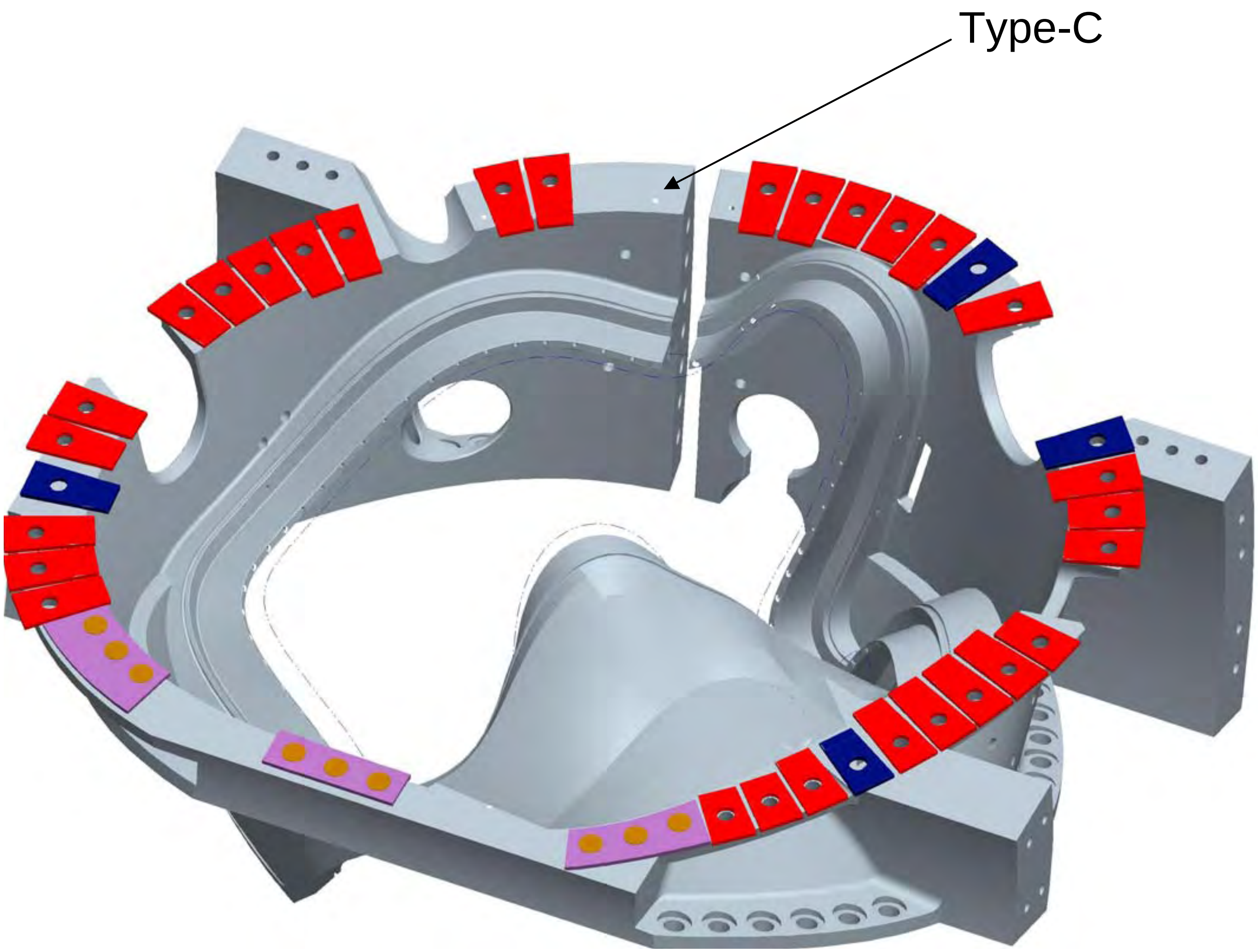


NCSX
National Compact Stellarator Experiment

BC Inboard Welded Shims

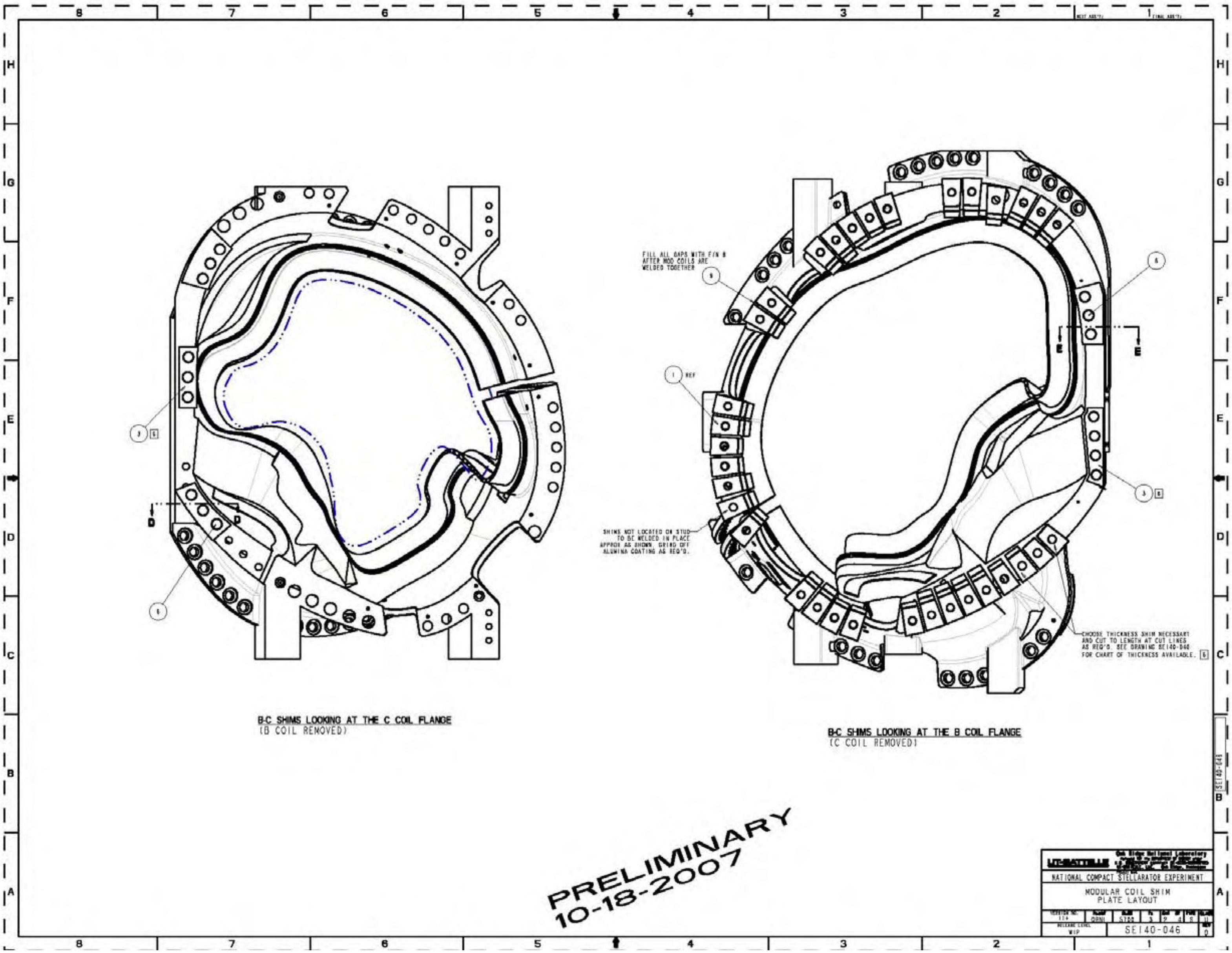


BC Inboard Welded Shims

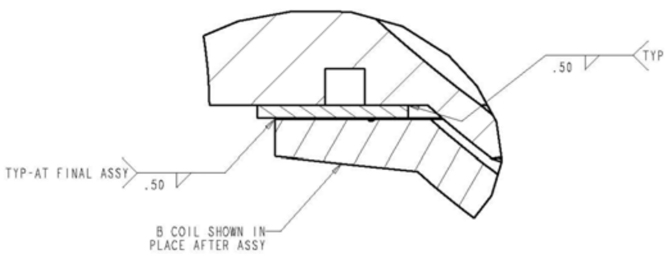


BC Inboard Welded Shims

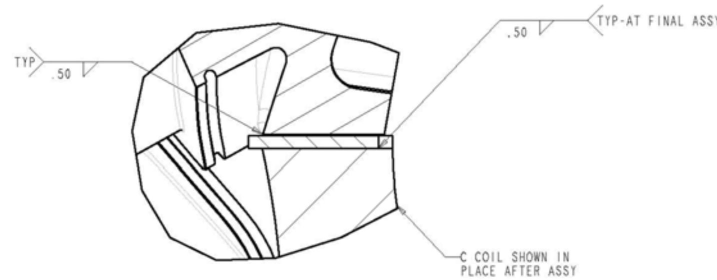
NCSX National Compact Stellarator Experiment



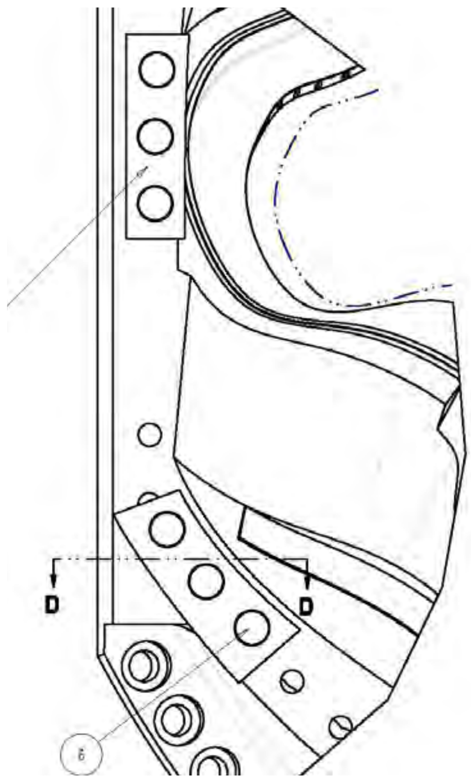
BC Inboard Welded Shims

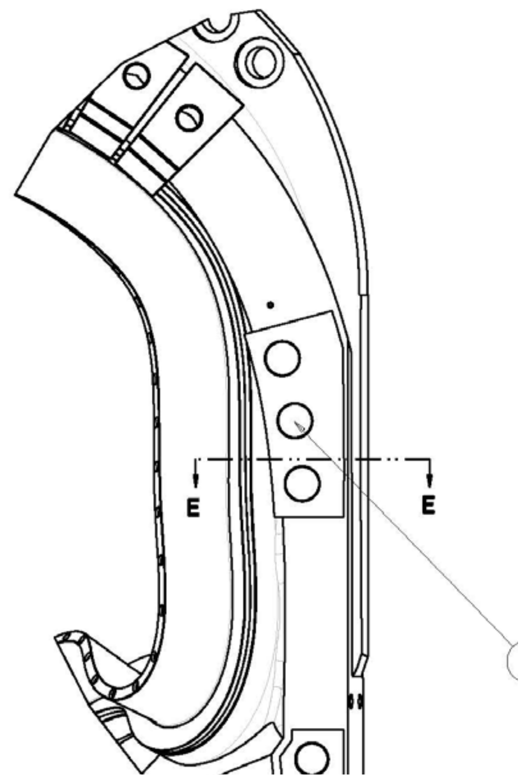


SECTION D-D
SCALE 0.50



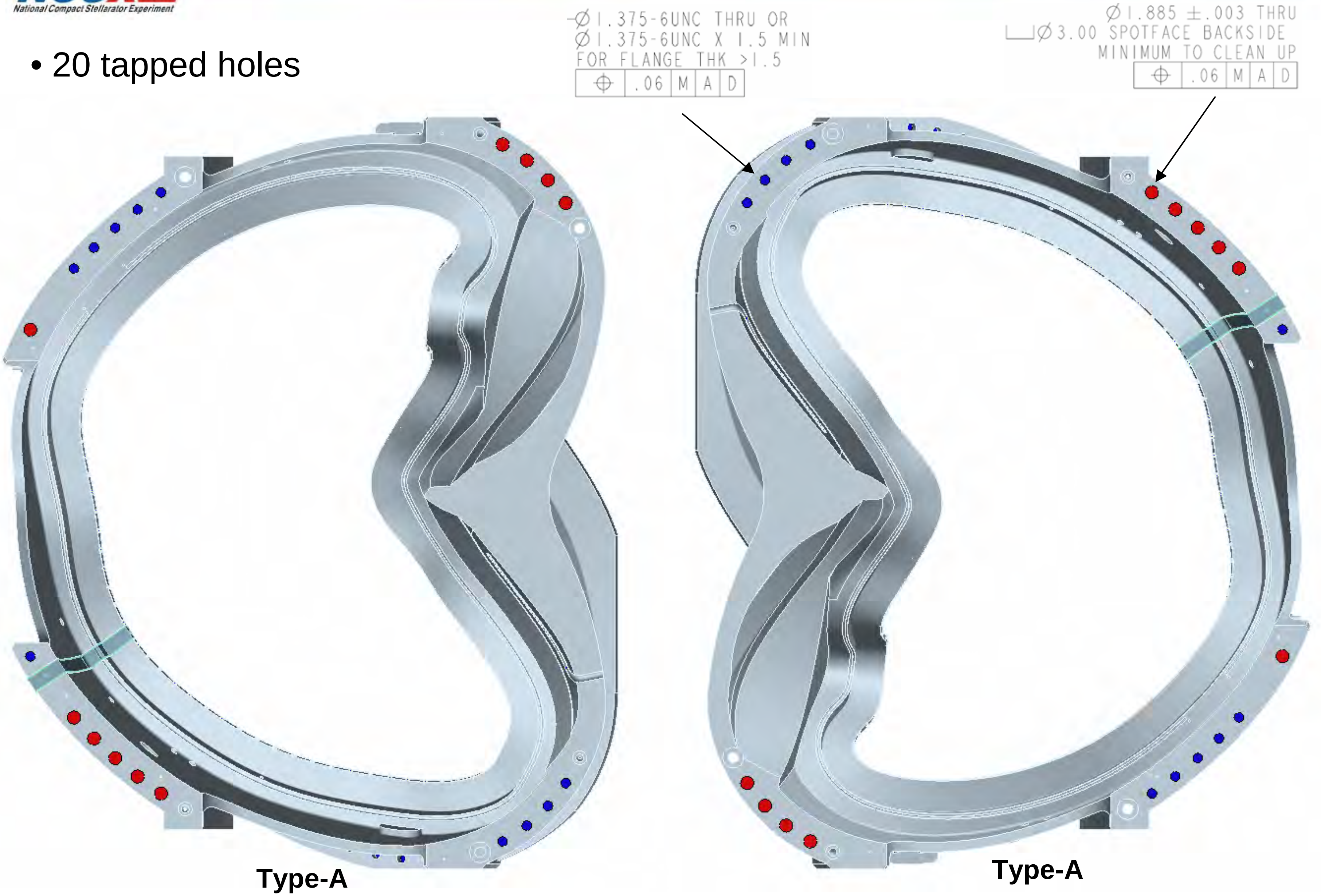
SECTION E-E
SCALE 0.50





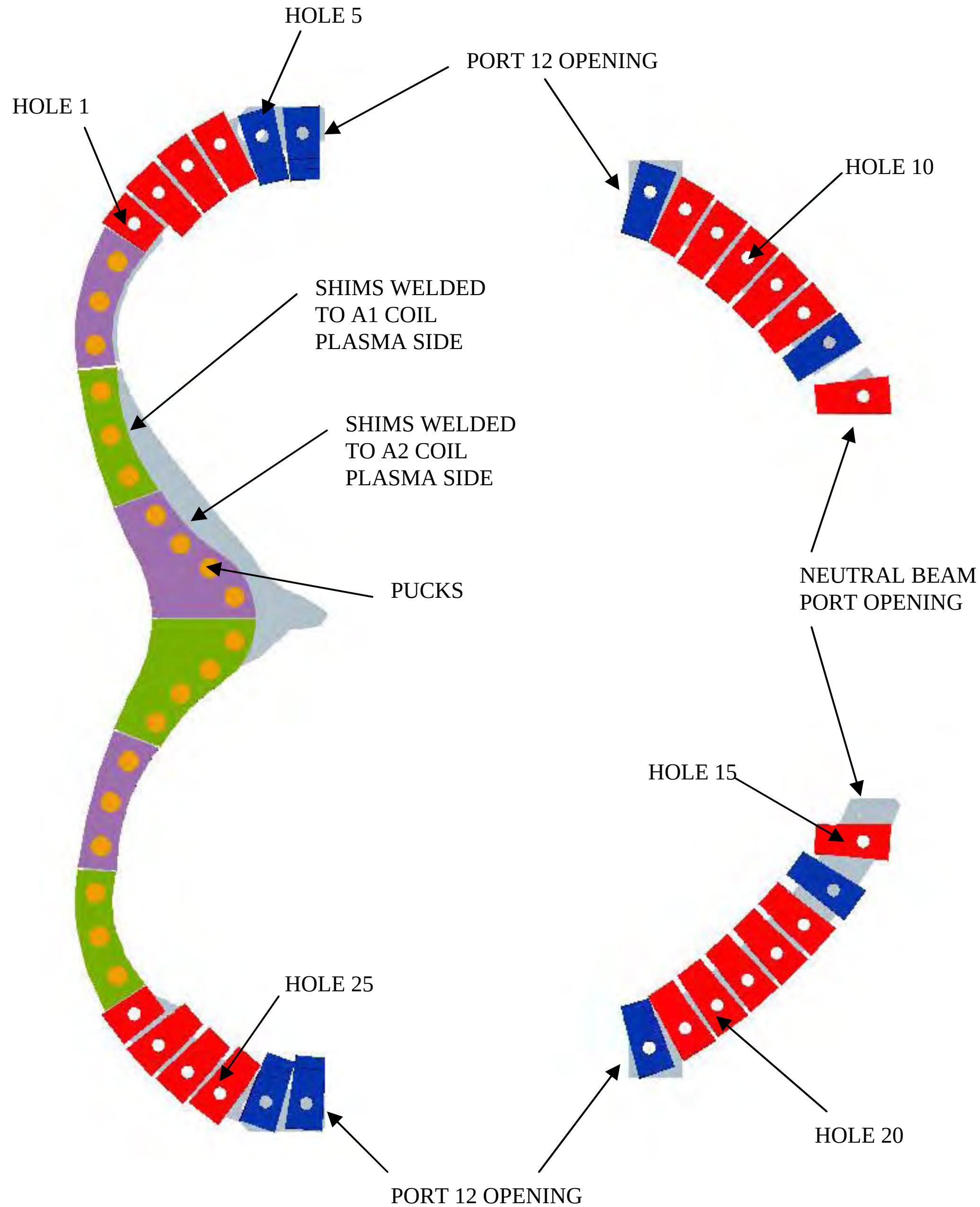
Interface A-A

- 20 tapped holes

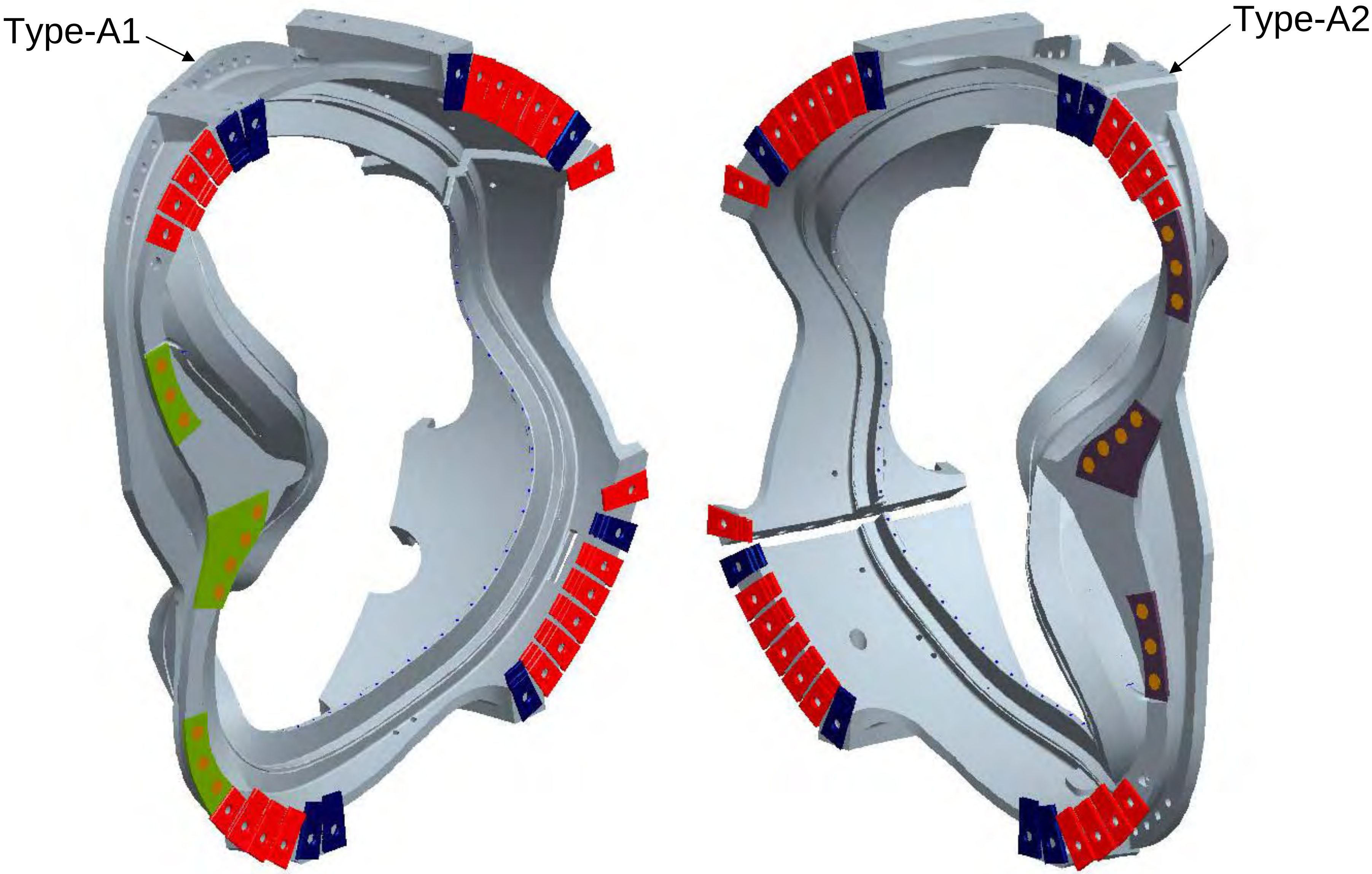


A-A FLANGE

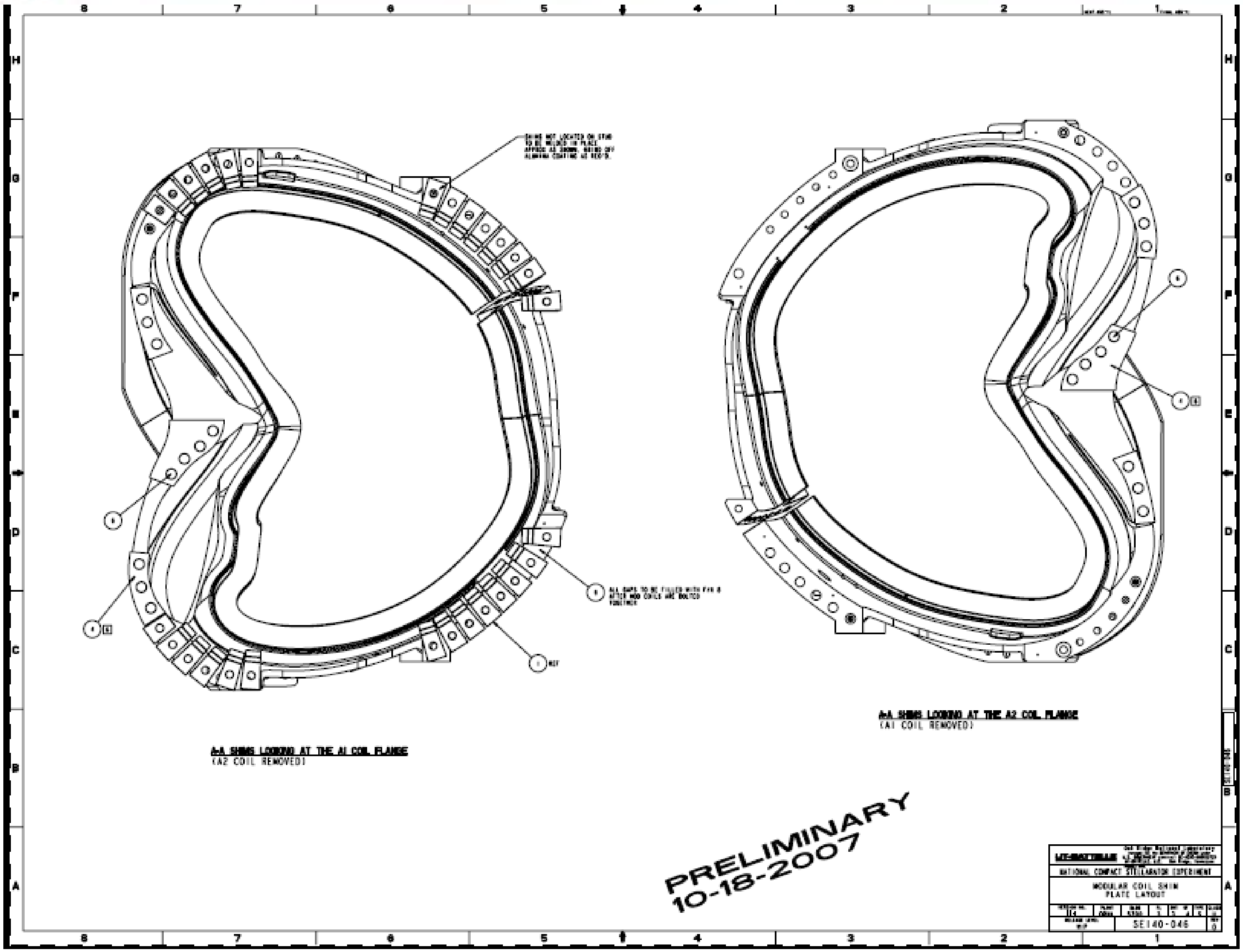
AA Hole #	Shim Length Hole to Bottom	No Bolt Shim
1	2.75	
2	5.00	
3	5.00	
4	5.00	
5		5.00
6		5.00
7		5.00
8	5.00	
9	5.00	
10	5.00	
11	5.00	
12	5.00	
13		5.00
14	5.00	
15	5.00	
16		5.00
17	5.00	
18	5.00	
19	5.00	
20	5.00	
21	5.00	
22		5.00
23		5.00
24		5.00
25	5.00	
26	5.00	
27	5.00	
28	2.75	



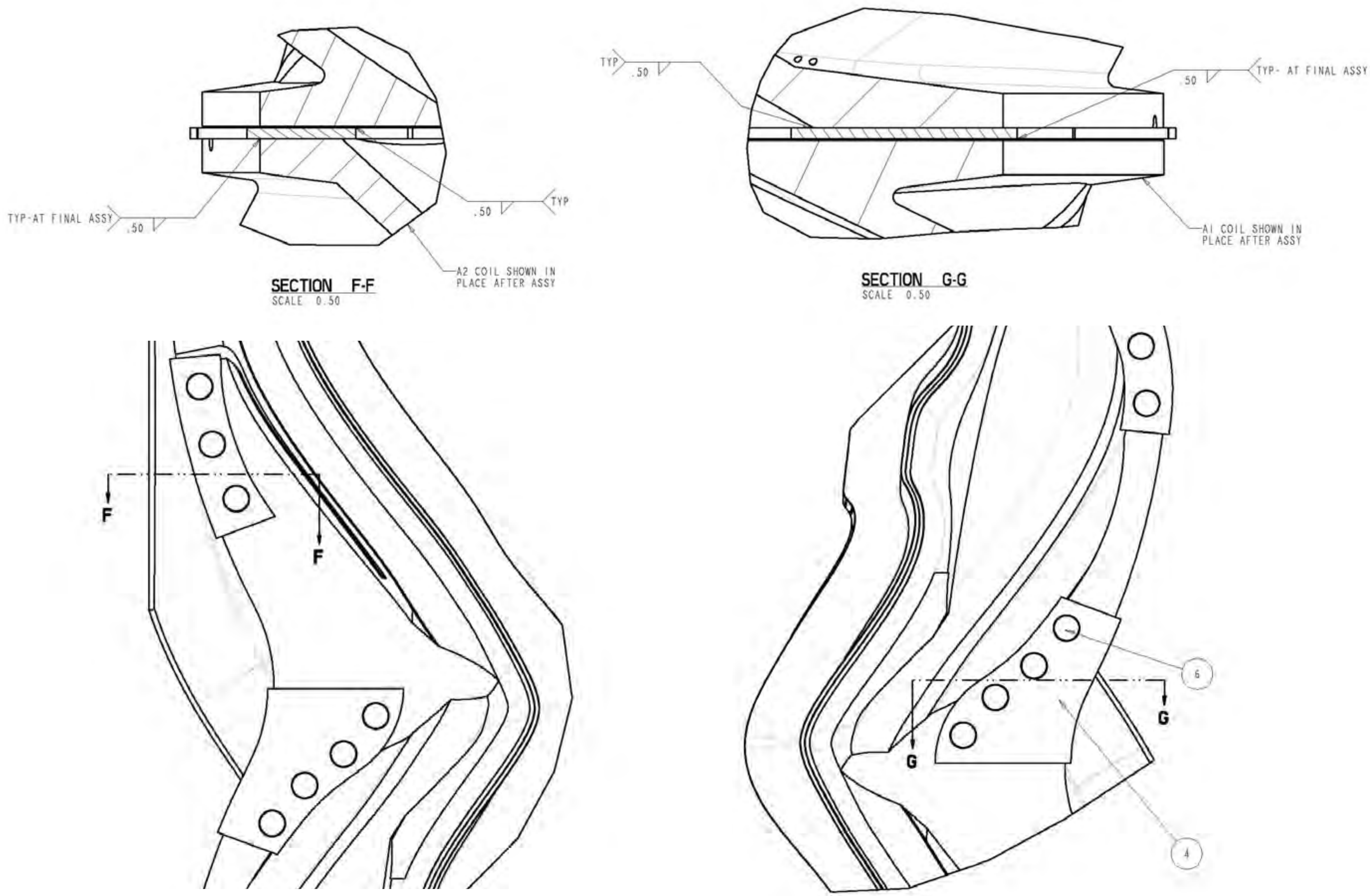
AA Inboard Welded Shims



AA Inboard Welded Shims

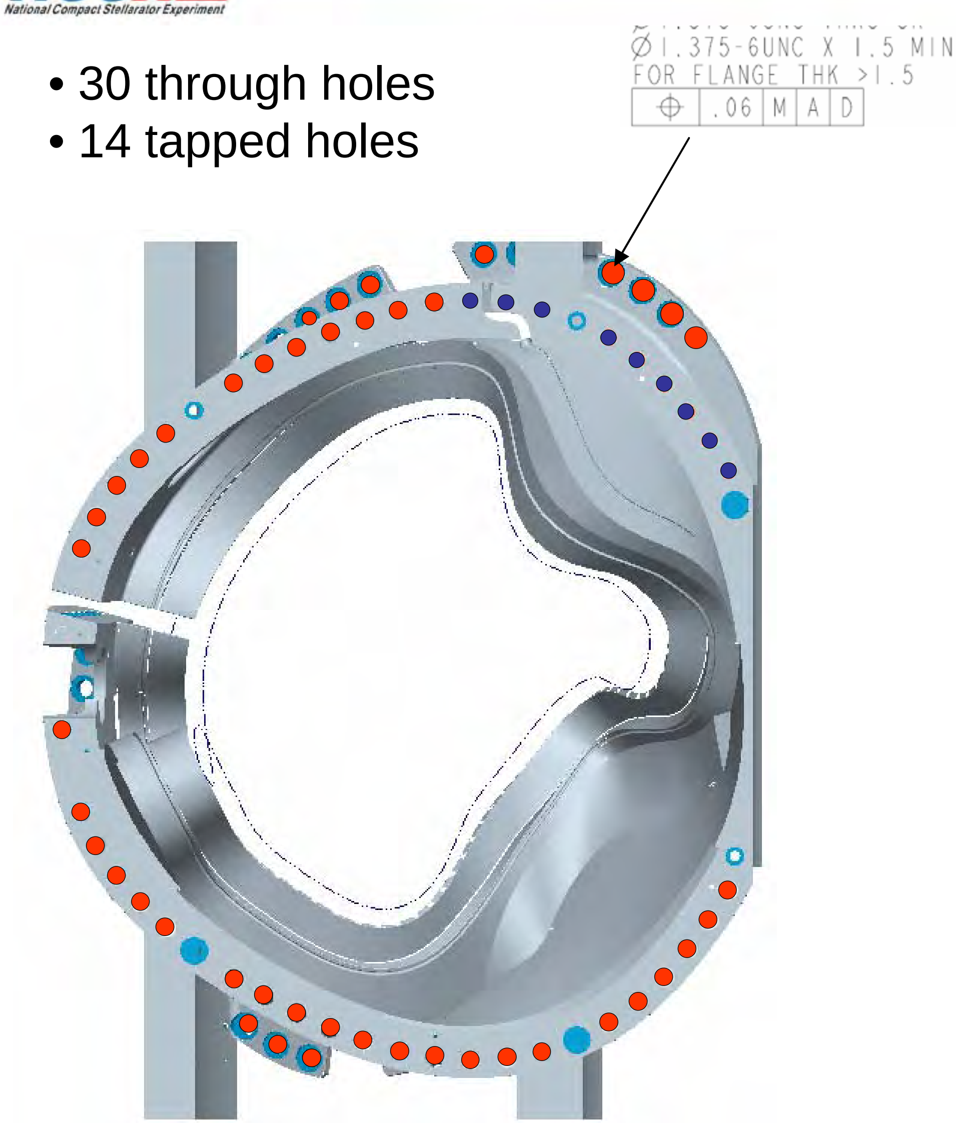


AA Inboard Welded Shims

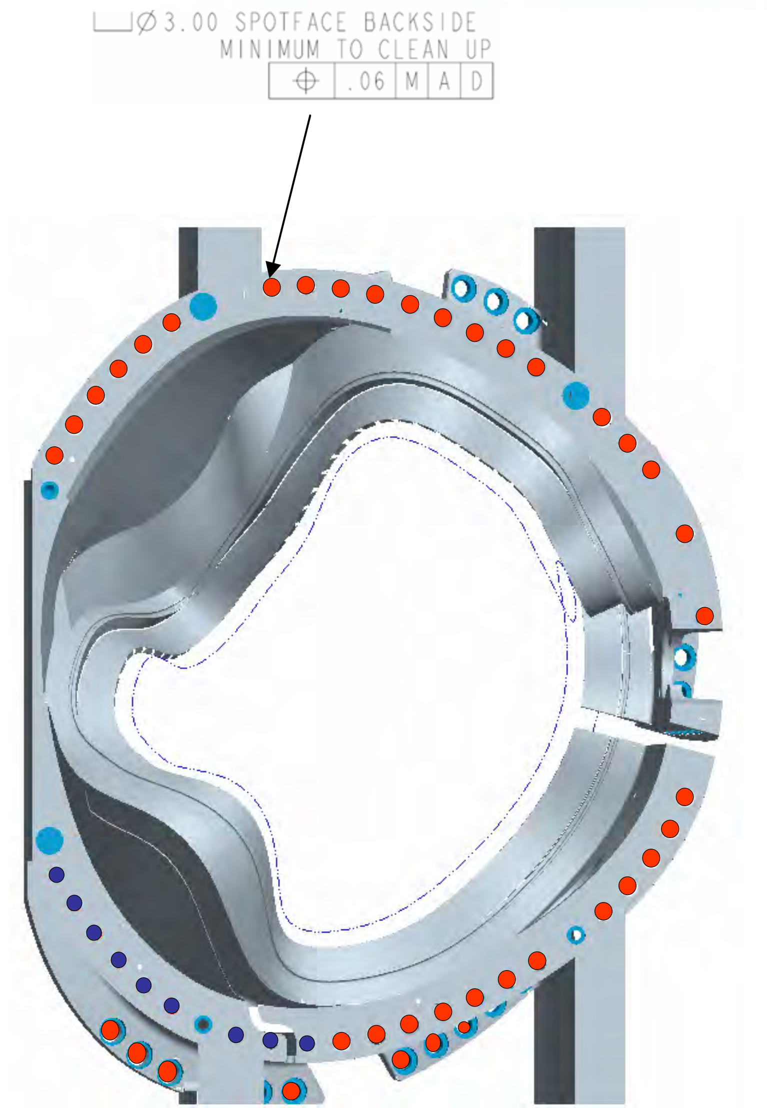


For Reference only Interface C-C

- 30 through holes
- 14 tapped holes



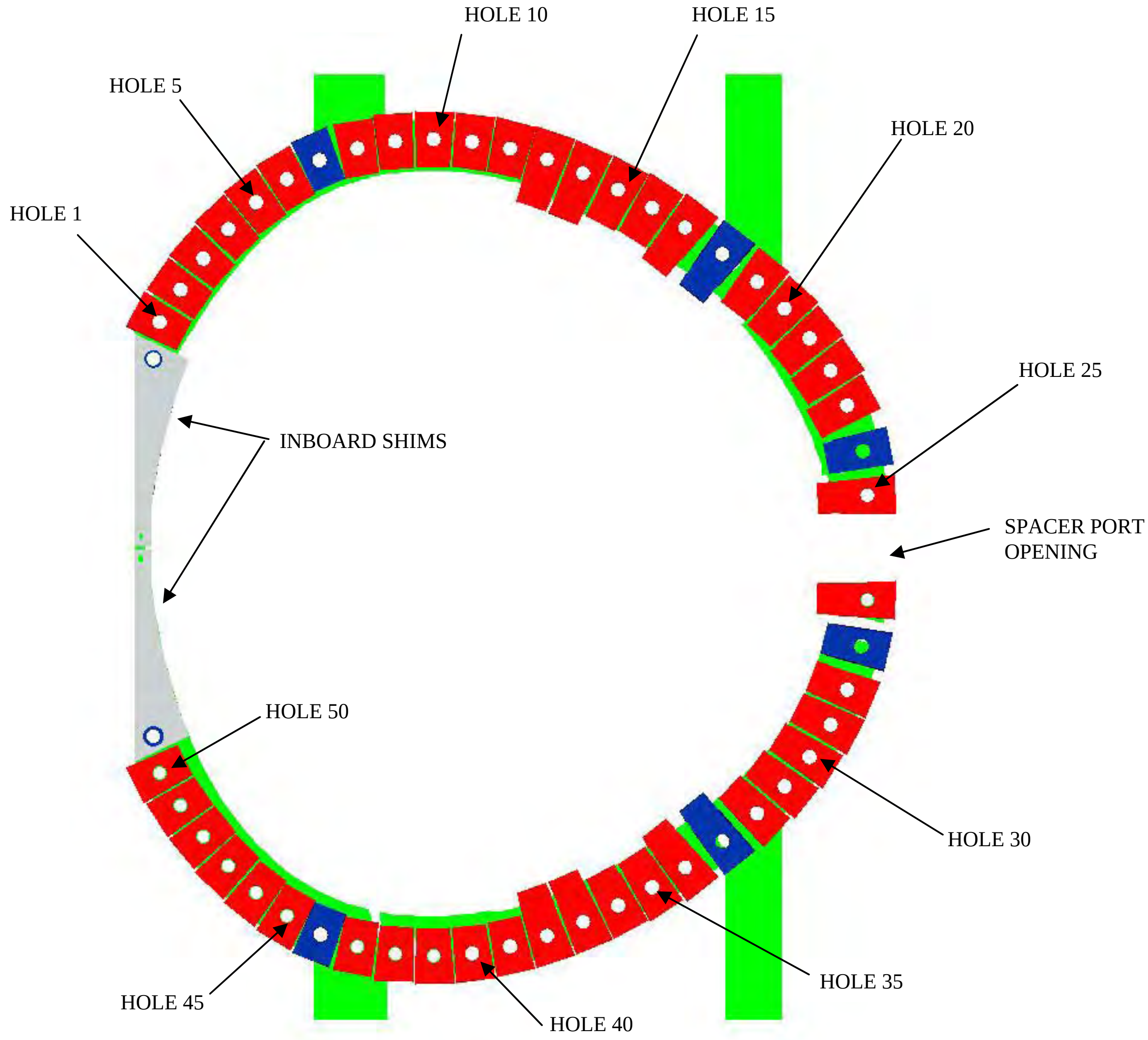
Type-C



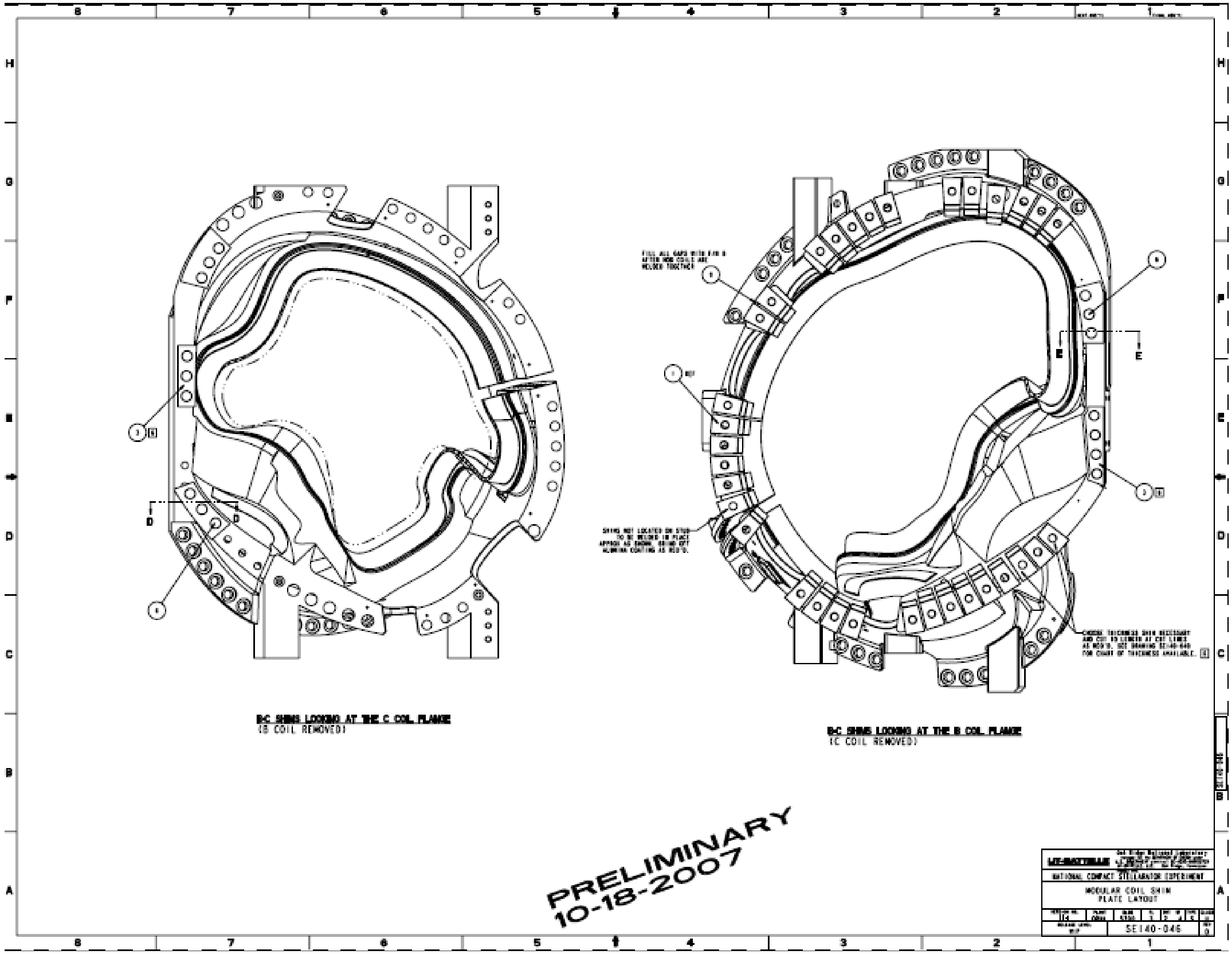
Type-C

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	

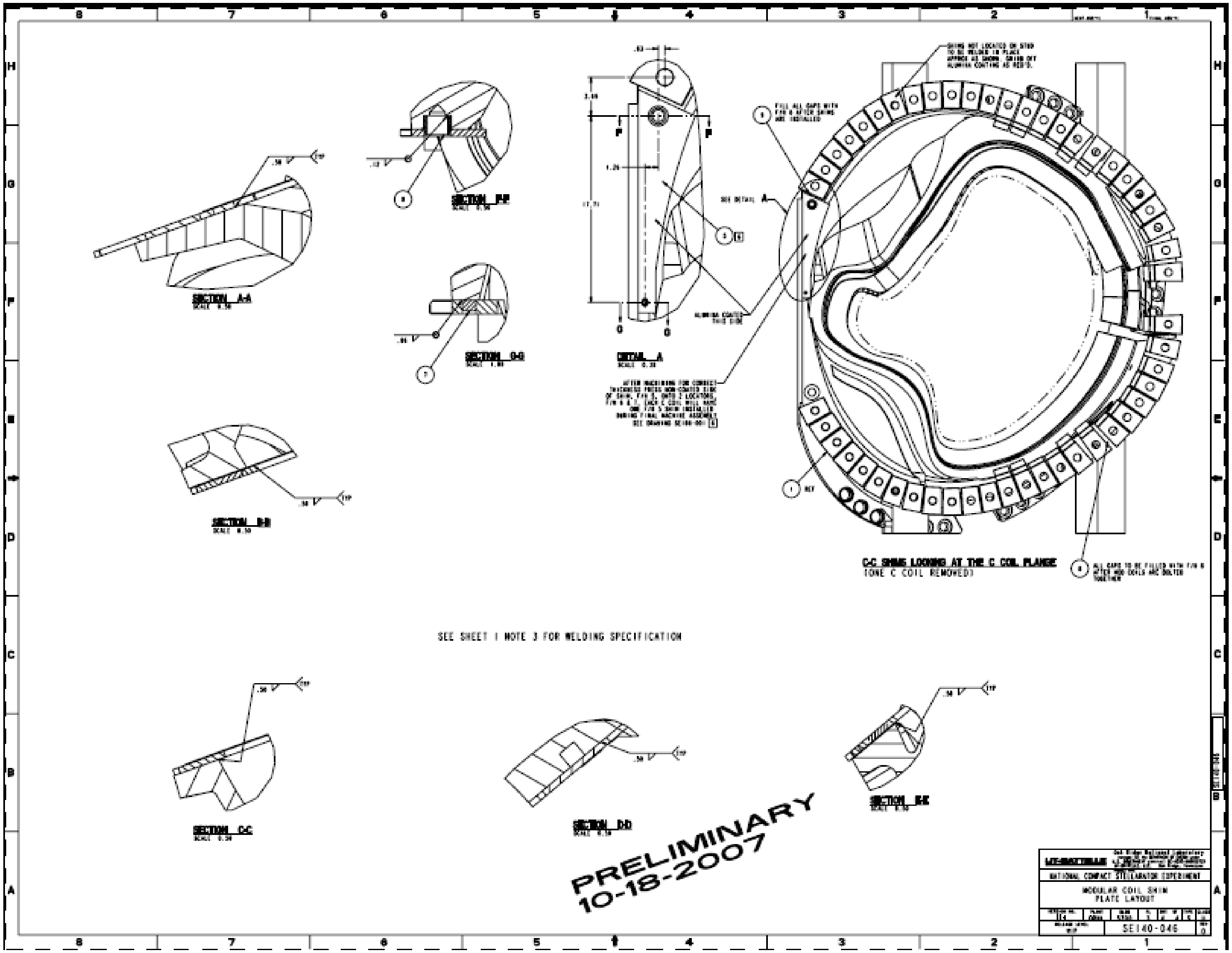
C-C FLANGE



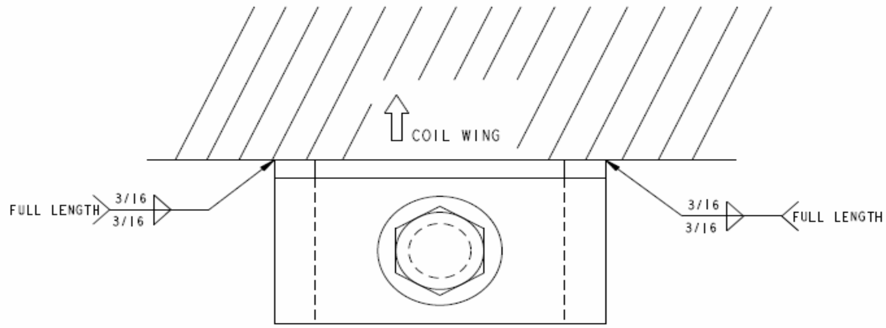
For Reference only Interface C-C



For Reference only Interface C-C

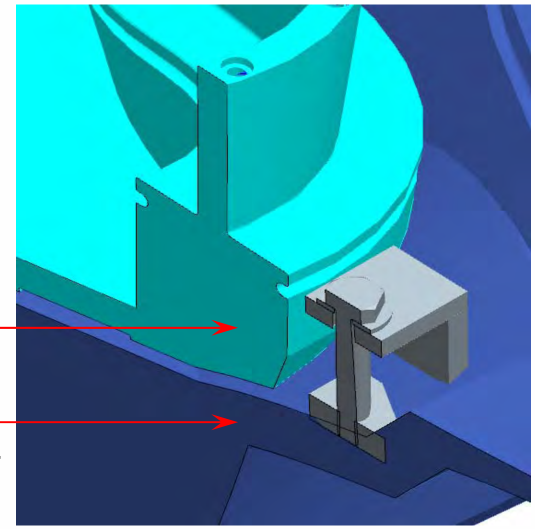


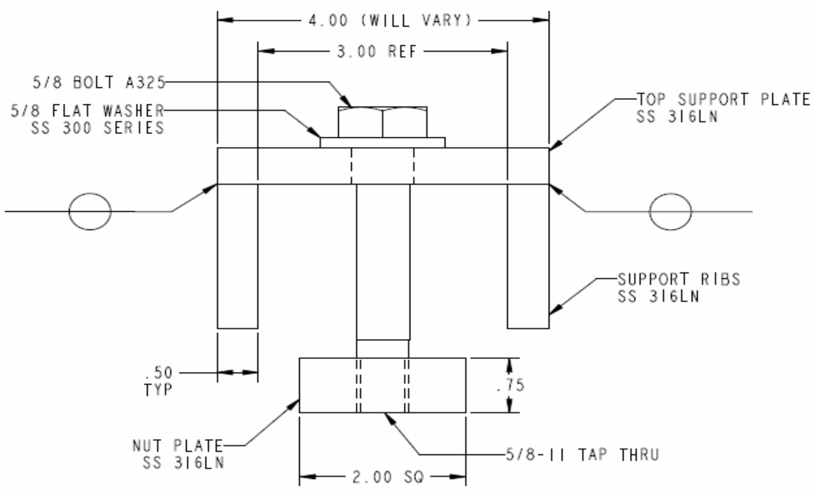
Wing support design

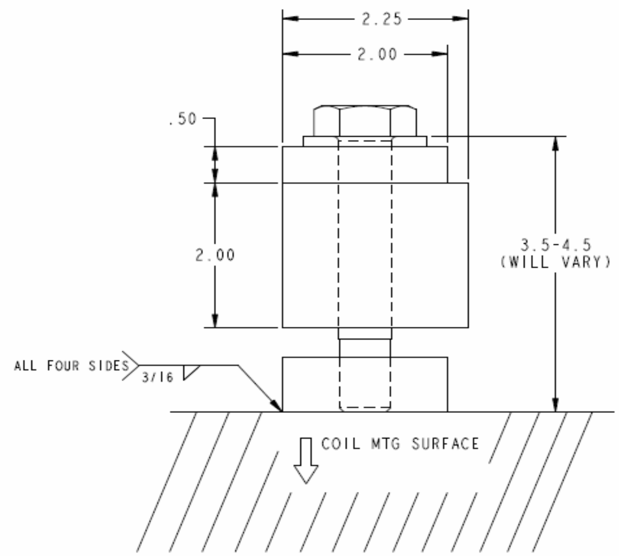


COIL WING

COIL MTG SURFACE







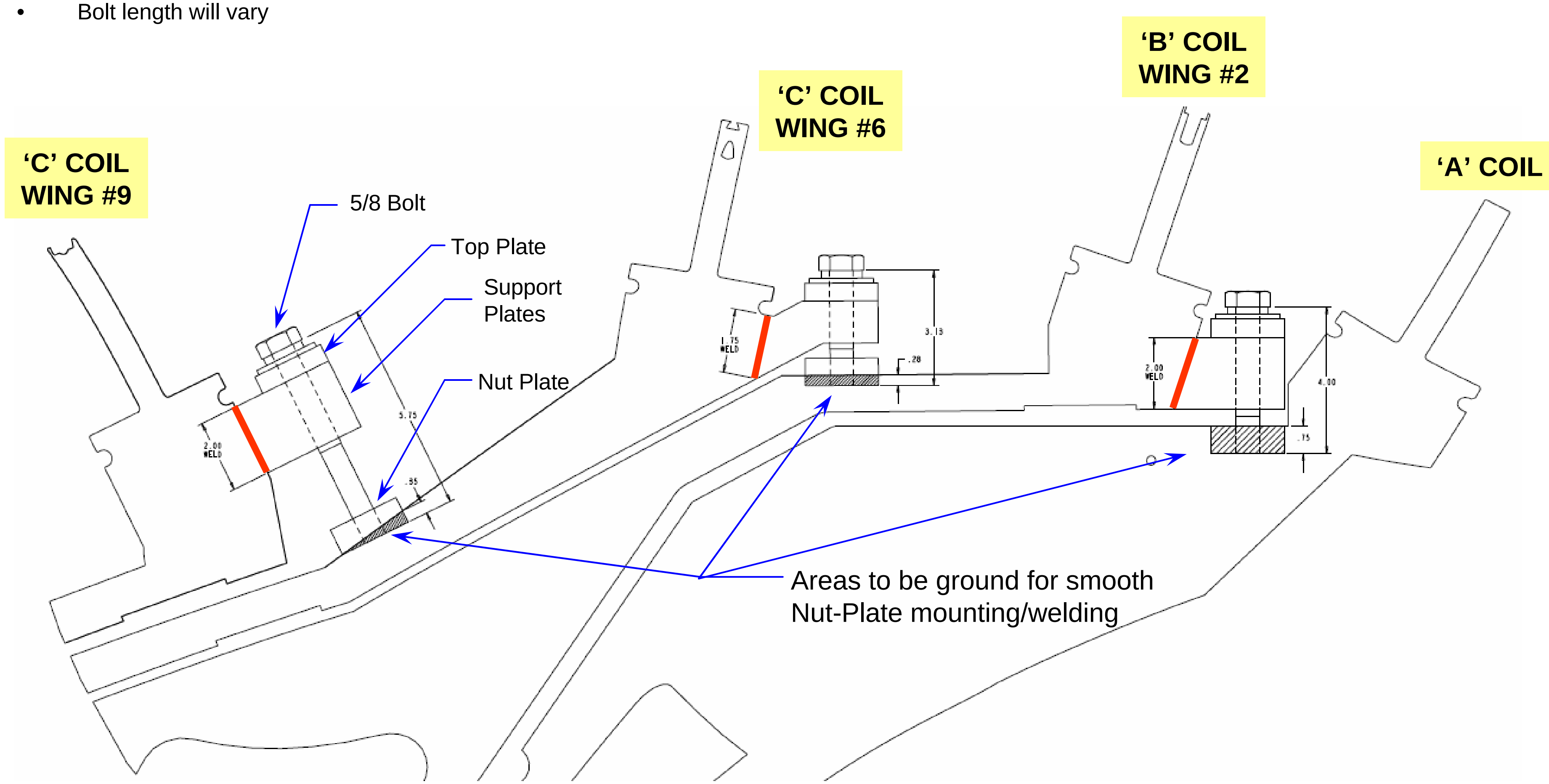
CONCEPT USING WELDED CHAIR WITH NUT-PLATE

WINGS # 2, 6 and 9

NCSX National Compact Stellarator Experiment

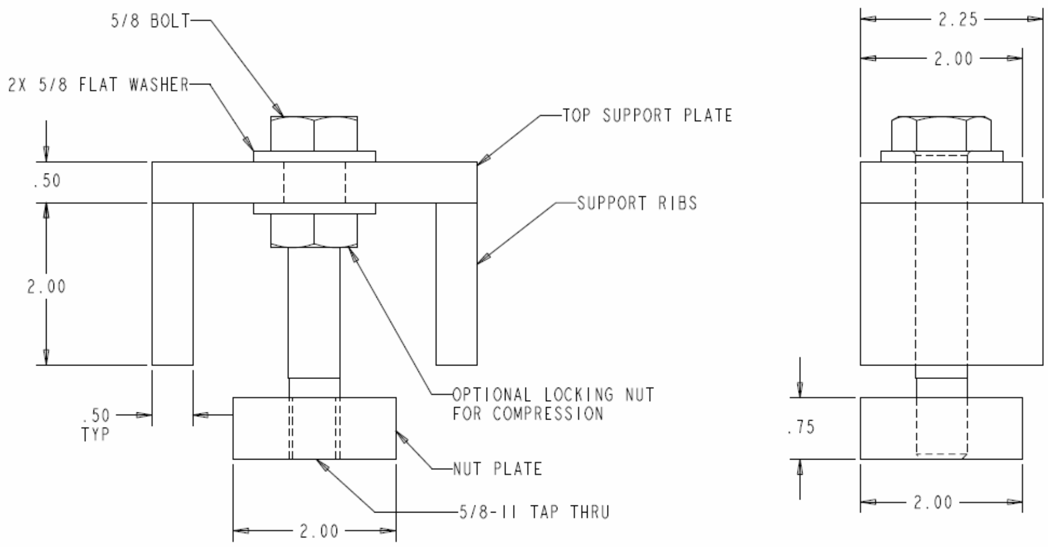
NOTES:

- Setup will vary for each wing and each chair weld on each wing
- Support plates can be fabricated to be ground to shape as necessary to match during installation
- This example shows only 3 specific areas – for depiction only
- Bolt length will vary



Bolt Tensile Stress Analysis

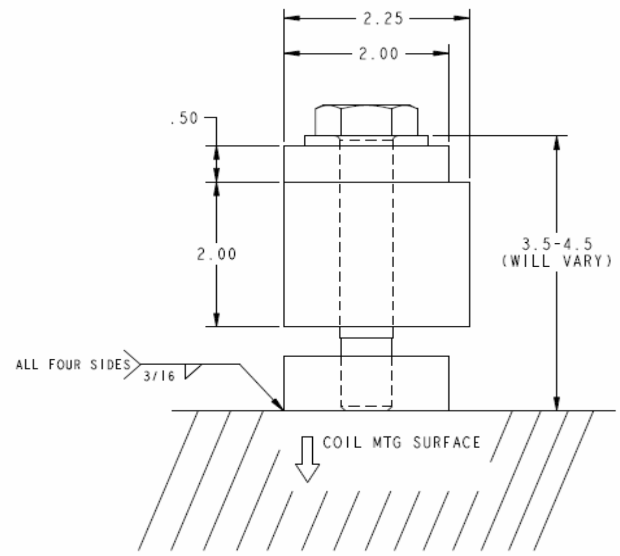
Total Bolt Load	10,000	
Nominal Bolt Diameter	0.625	in
Number of Threads per inch	11	threads / in
Bolt Tensile Stress Area	0.2260022	in^2
Bolt Tensile Stress	44,247	lb / in^2
Allowable Tensile Stress	45,000	lb / in^2



Wing support design

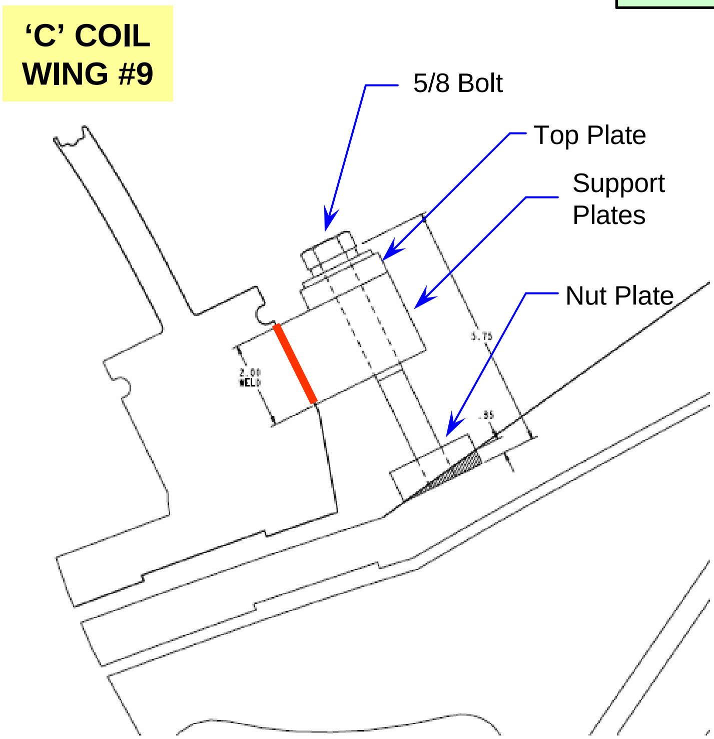
Nut Plate Weld Analysis

Total Load	10,000	lbs
Weld Length	8	in
Weld Size	0.1875	in
Effective Weld Throat	0.1326	in
Nut Plate Shear Stress	9,428	lb / in^2
Allowable Shear Stress	14,800	lb / in^2



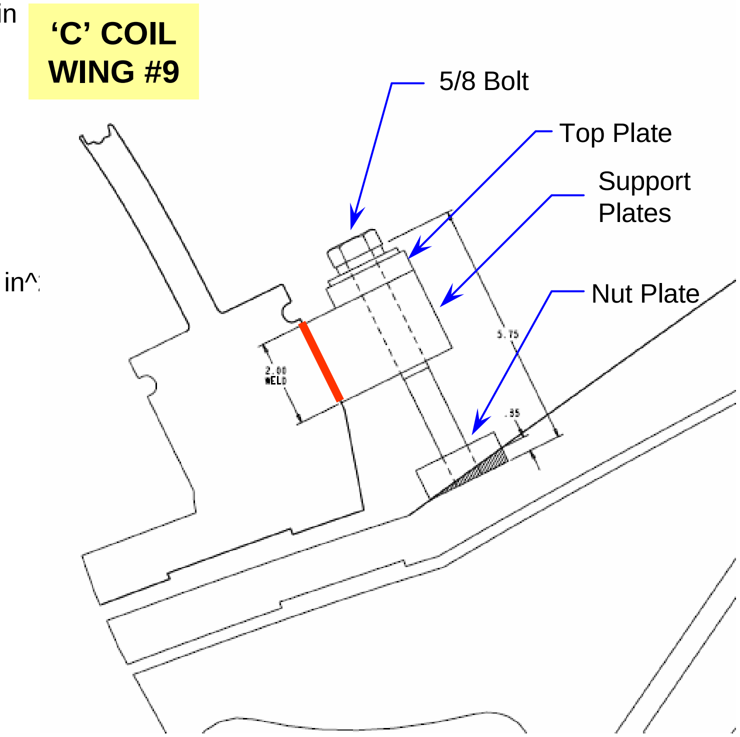
Chair Weld Analysis - 2" Straight - Shear Stress

Total Load	10,000	lbs
Weld Length	8	in
Weld Size	0.1875	in
Effective Weld Throat	0.1326	in
Chair Weld Shear Stress	9,428	lb / in^2



Bending Stress

Weld Size	0.1875	in
Cantilever	1.2500	in
Total Load	5,000	lbs
Moment	6,250	lb * in
Weld Length	2.5	in
Distance between welds	0.5	in
Unit Second Moment of Area	2.6041667	
Second Moment of Area	0.3452148	
Bending Stress	22,631	lb / in^:



Analysis Documentation

- Modular coil asm design basis is defined by 5 analysis reports:

  HM Fan, Nonlinear Analysis of Coil and Shell Structure, NCSX-CALC-14-001, APPROVED
  HM Fan, Analysis of Integrated Structure, NCSX-CALC-14-003, APPROVED
  K Freudenberg, Modular Coil Thermal Analysis, NCSX-CALC-14-002, DRAFT
  K Freudenberg, Nonlinear Modular Coil Analysis, NCSX-CALC-14-004, DRAFT
  D Williamson, Modular Coil Failure Modes Analysis, NCSX-FMEA-14-002, DRAFT

- Additional analysis reports are planned before Design Closeout:

  K Freudenberg, Outboard Bolted Joint Analysis, NCSX-CALC-14-006, DRAFT
  ➡ K Freudenberg, Modular Coil Inboard Shims Analysis, IN PROGRESS
  D Williamson, Modular Coil Leads Structural Analysis, PLANNED

Quick weld allowable calculation

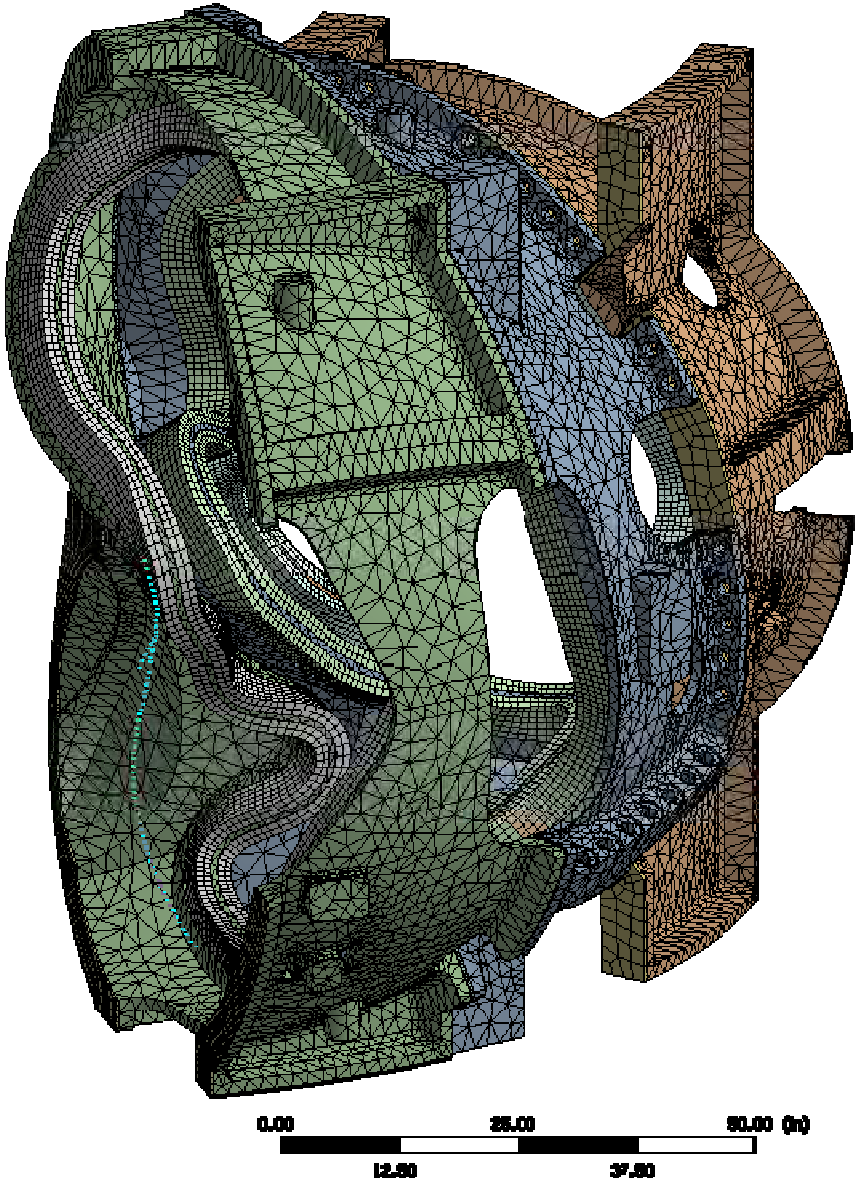
- Sm = 2/3 Sy at temp or 1/3 Sult for all materials
- Sy = 93.2 ksi for Stelalloy but weld since Sult is 157.5 -> Sm = 52.5 based on weld wire.
- Knockdown factor of .6 applied for visual inspected welds. → **31.5 ksi**. Which is our max stress intensity we can incur statically.

- Shim and pucks will be constructed of 316 LN stainless steel.
  - Sy = 131 ksi at 77K *
  - Sult = 205 ksi at 77K *
  - ► **Sm = 68 ksi (1/3 Sult)**

* **Low-Temperature Fatigue of 316L and 316LN Austenitic Stainless Steels** J.-B. VOGT, J. FOCT, C. REGNARD, G. ROBERT, and J. DHERS 1991

New Global Model for welds

NCSX National Compact Stellarator Experiment

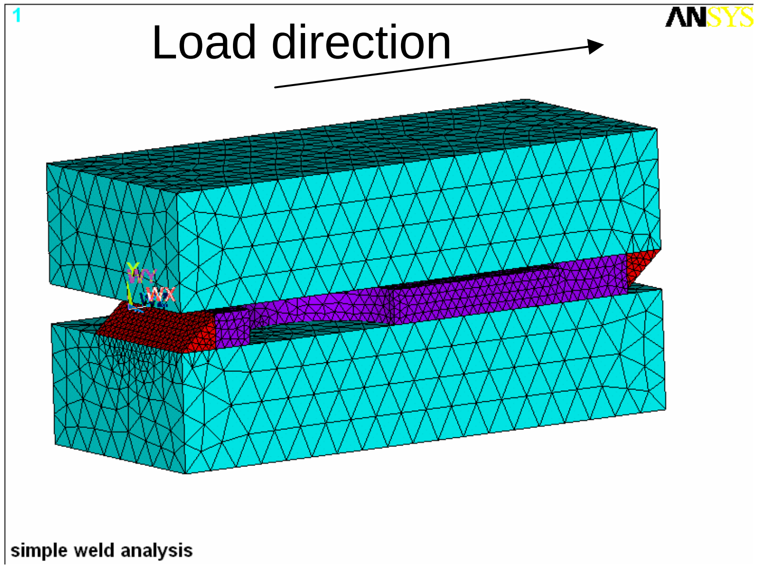


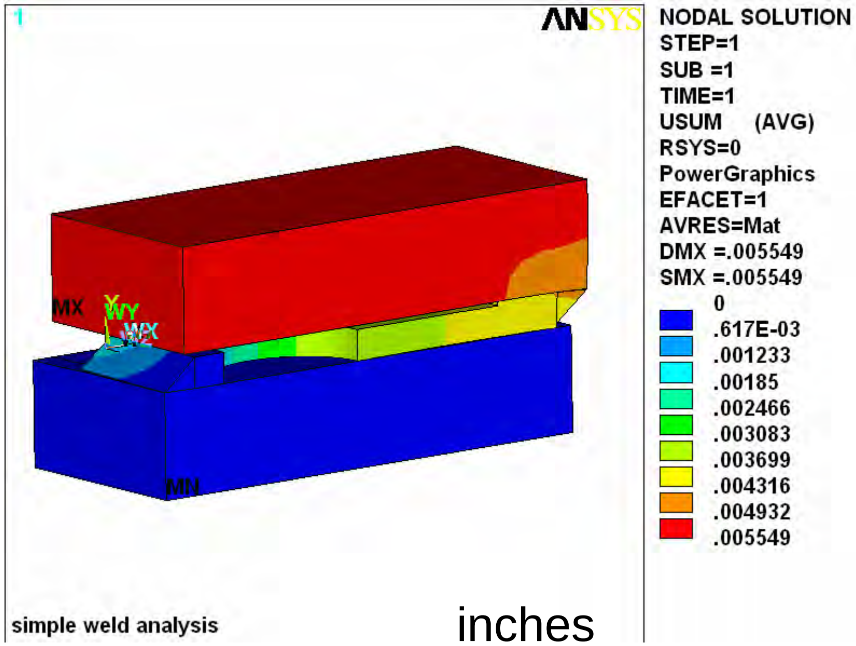
- Weld Elements are placed in the model on the each flange of interest in turn. (AA, AB, BC)
- Bolt holes and bolts taken out of all flanges except the one being studied (bolts may be added latter).
- This method locks up the outboard side of the global model with bonded contact but has the inboard compression pucks run with frictionless sliding (Keyopt 12 = 0). The weld takes all of the shear from the interface.
- Material Properties of weld match that of shim and castings.
- The analysis has only examined the 2T high beta case. (supposedly the worst EM load case.)
- A detailed sub-model of the in-board leg, including proper segmentation and filet weld shape may then be constructed on flanges where stress is deemed an issue.

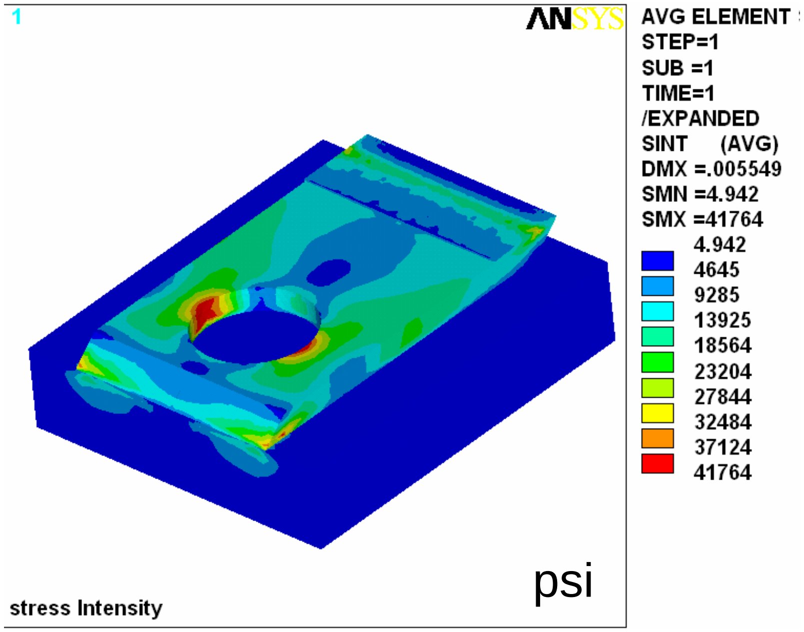
Quick check FEA models

Geometry		
gap between shims	0.25	in
shim width (W)	4	in
shear shim thickness (t)	0.438	in
compressive puck thickness (pt)	0.5	in
compressive puck diameter (pd)	2	in
Hole diameter(d)	2.1	in
Shim Length (L)	6	in
weld size	0.309	in

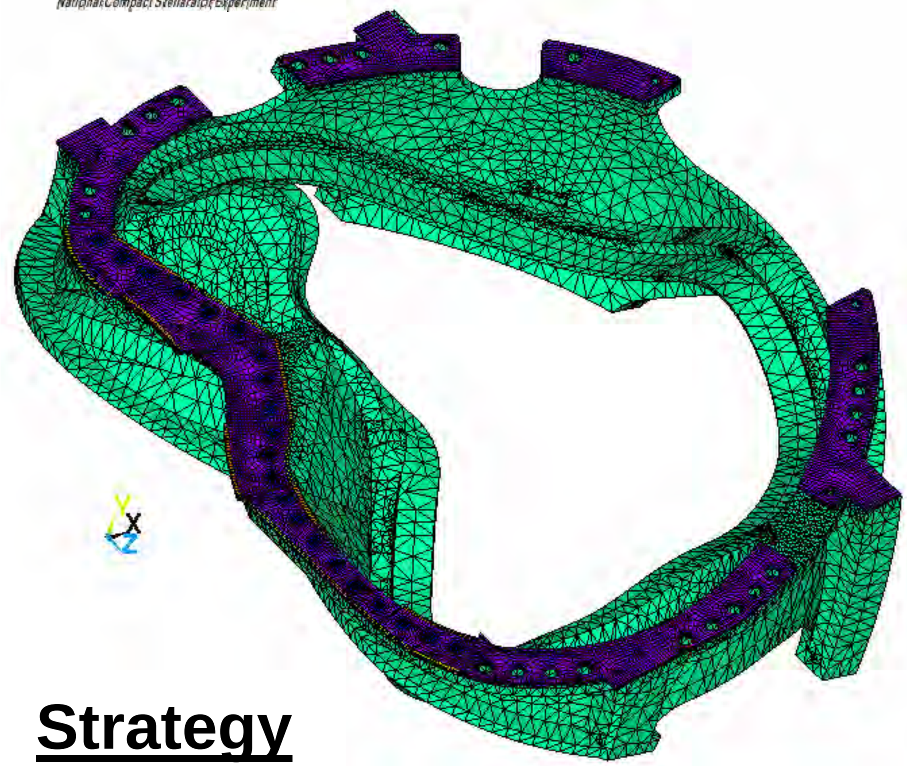
Applied average shear force = 4.2 Kips/in

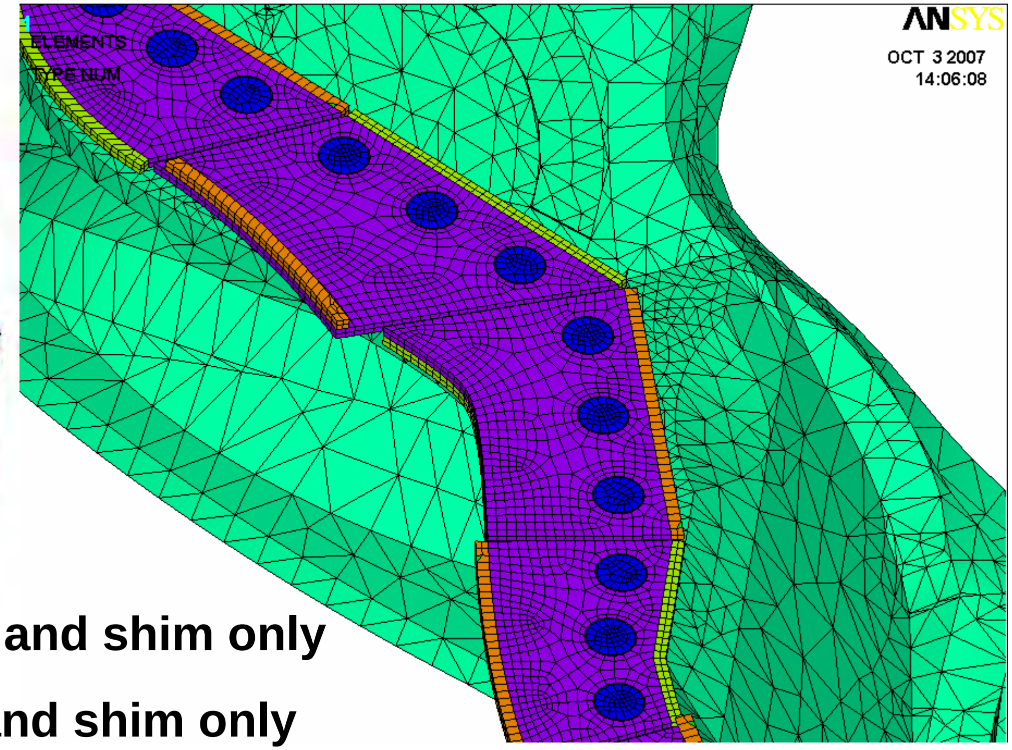






Global Model mesh of weld interface (AB)

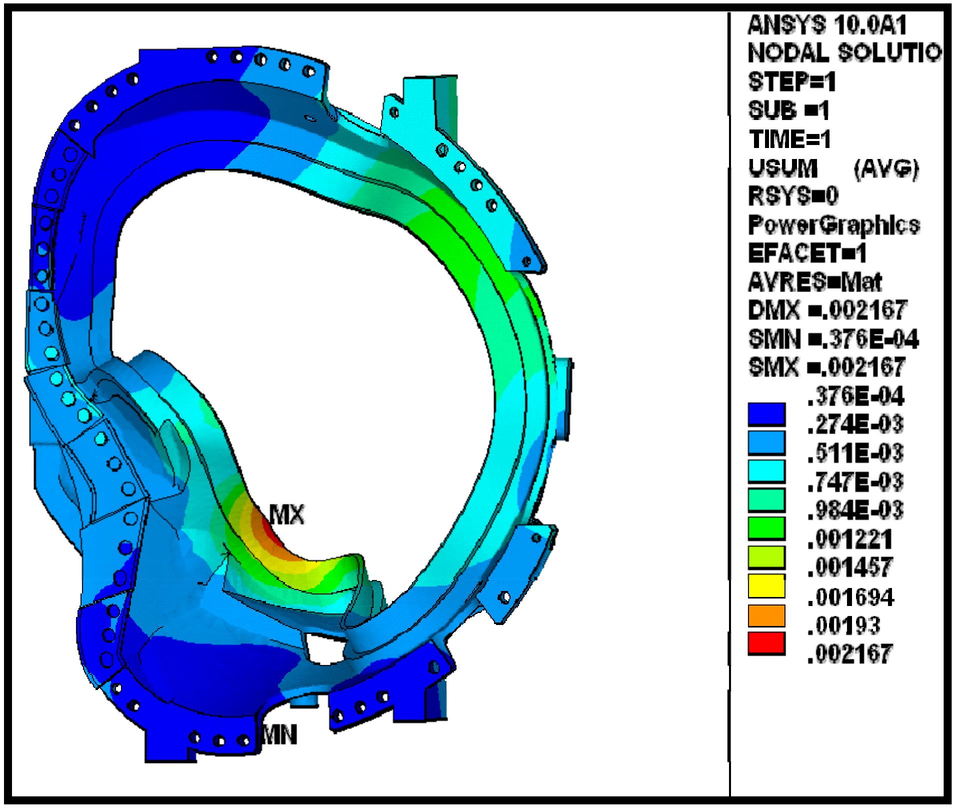




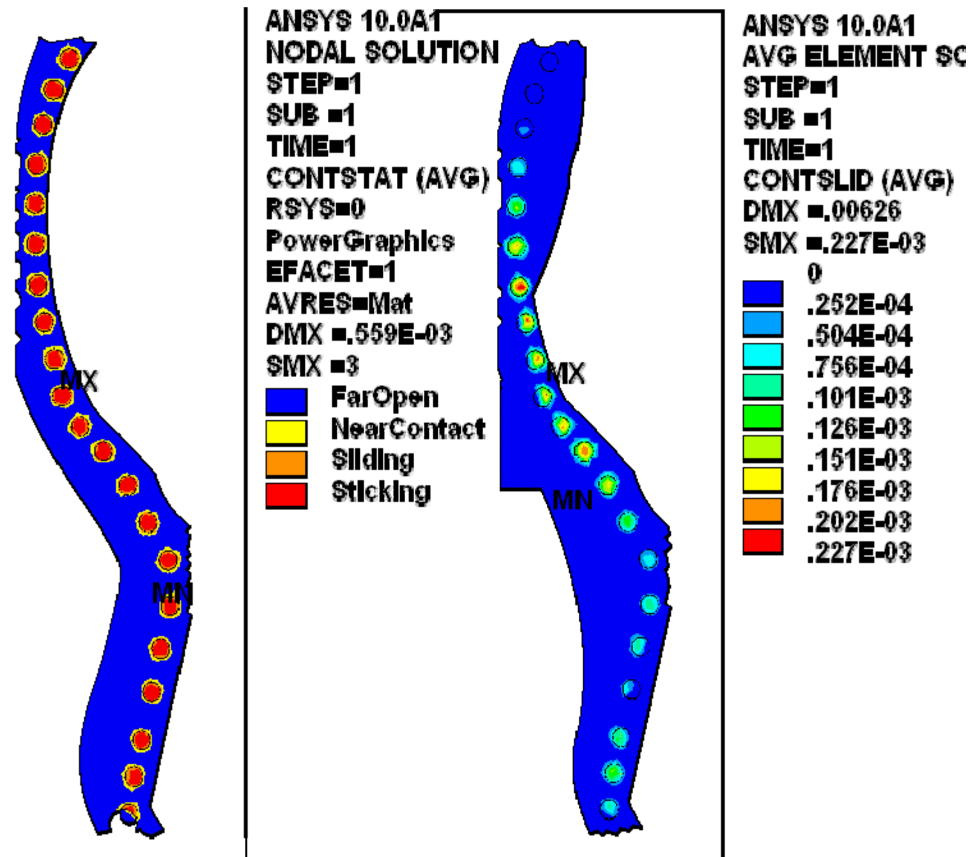
Strategy

- Orange welds connect to B casting and shim only
- Green welds connect to A casting and shim only
- Blue pucks carry compressive loads via frictionless interface on puck to B flange (blue pucks are glued to the A flange)
- Pucks are not connected to the shim.
- Shim in weld area will only connect to the A flange using frictionless contact and not be connected to the B flange at all (no compression carried by shim)

AB Deformation and puck check



Global Deformation. (meters)

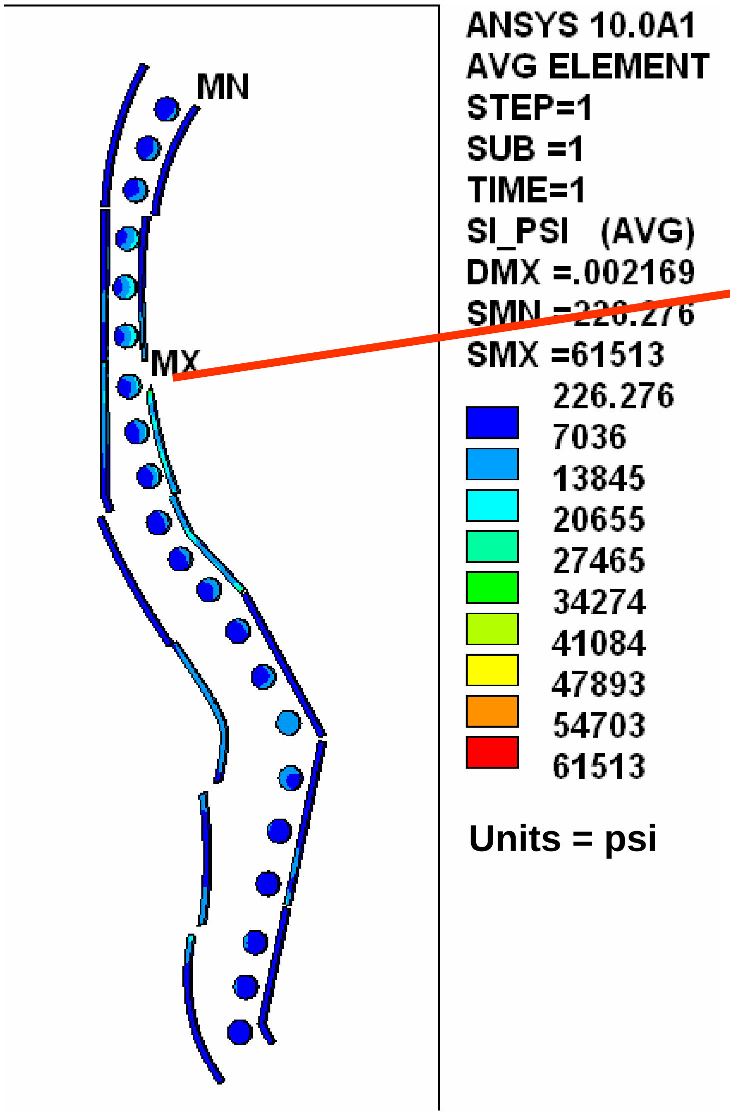


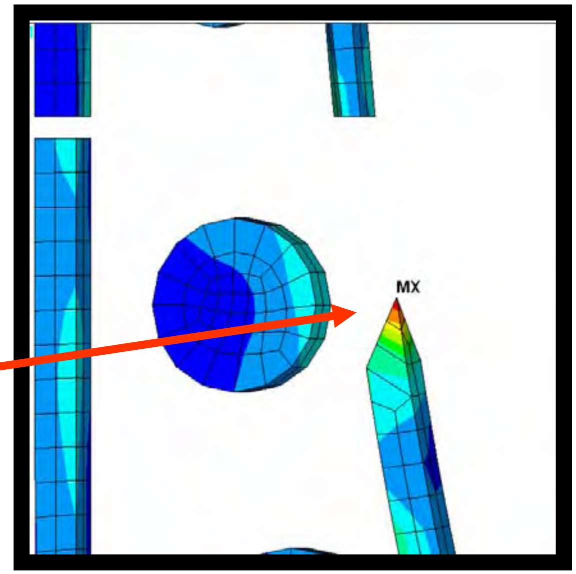
Pucks are stuck on B flange

Pucks slide on A flange (0.227 mm)

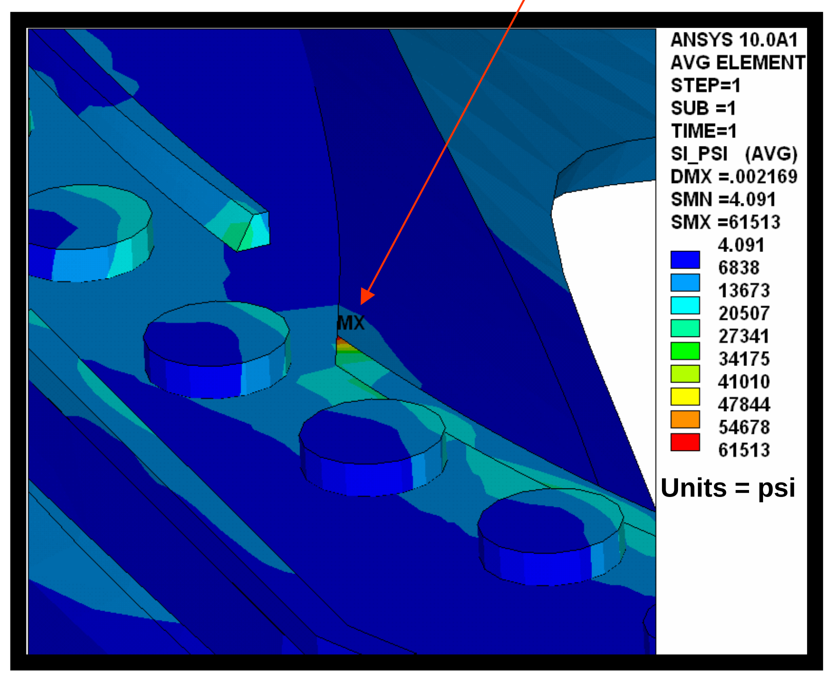
The pucks are not connected to shim and the shim is not connected to either flange in the welded region.

Stress Intensity on welds and pucks

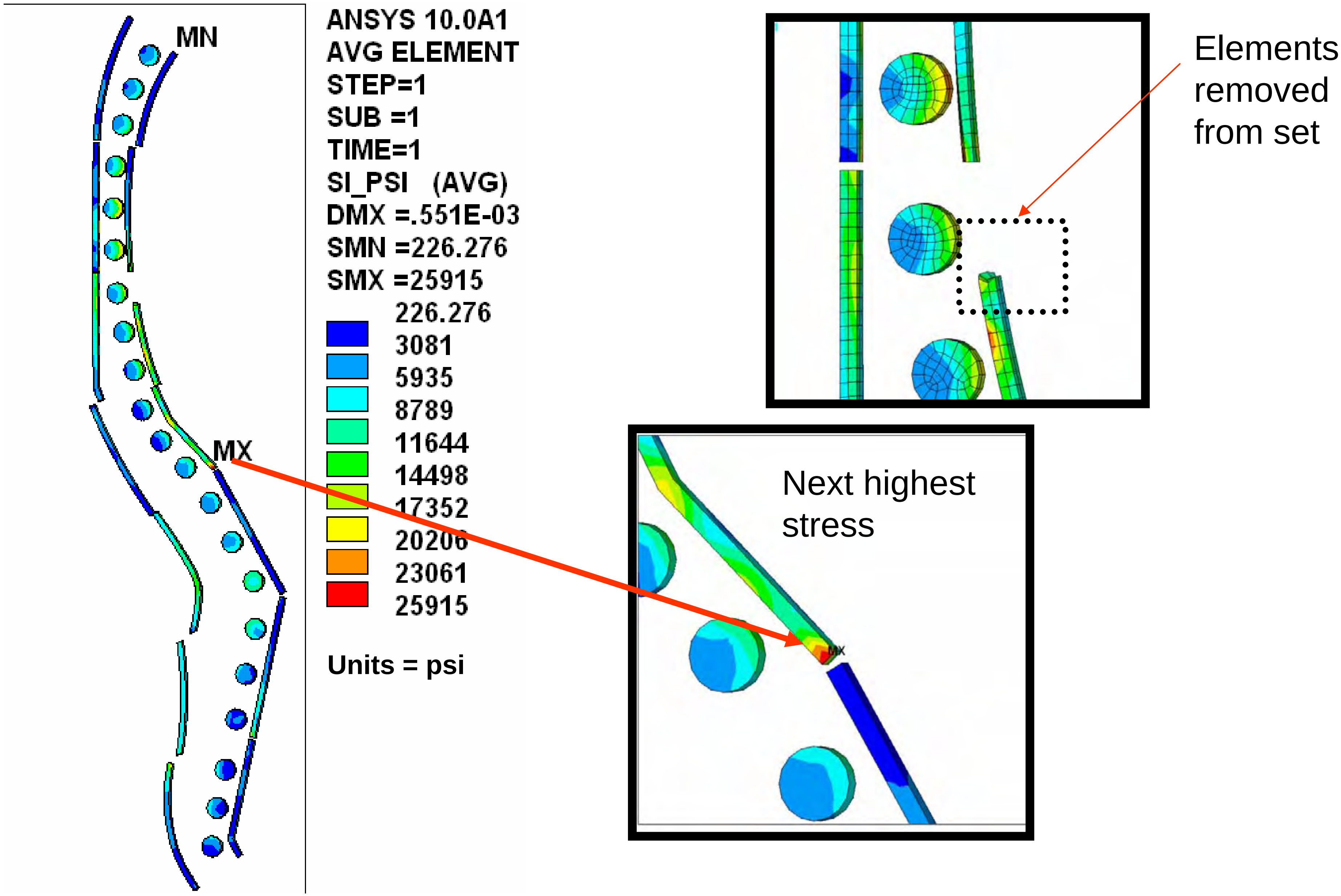




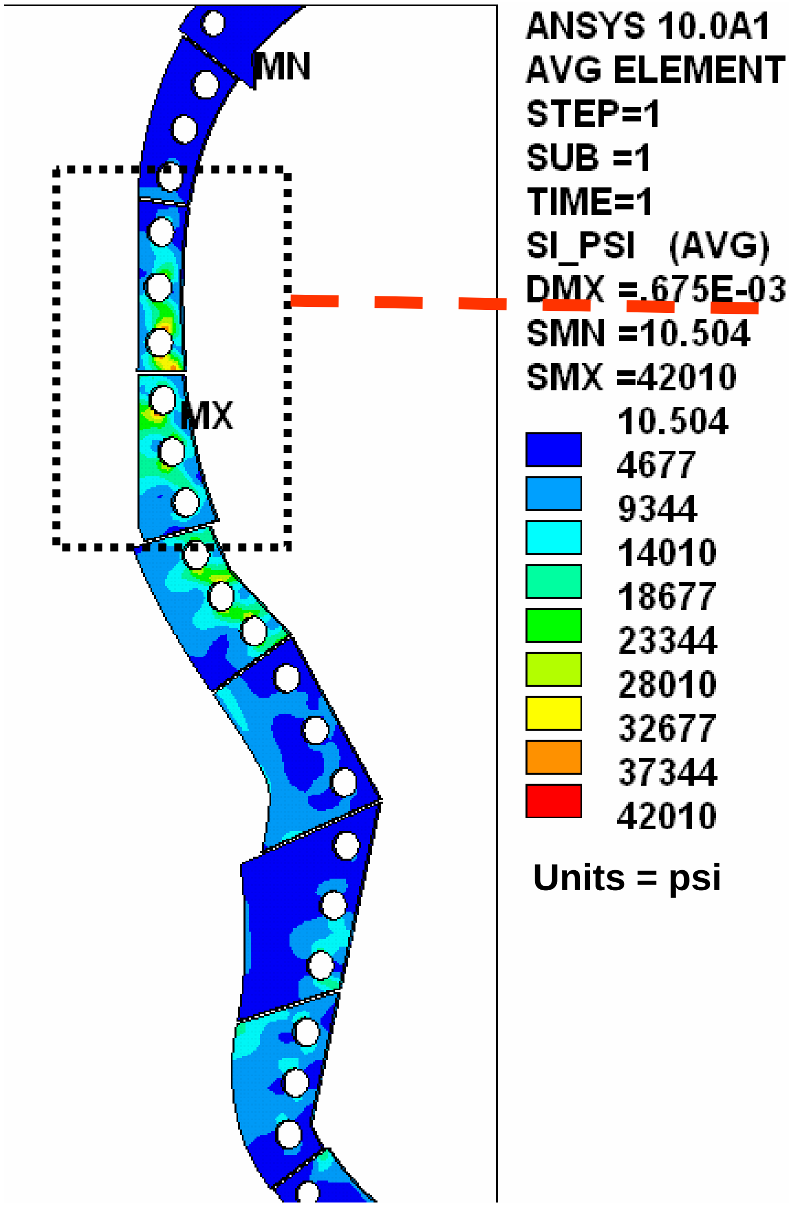
As with previous weld incarnations, a very peaky weld stress occurs on the corner edge of a weld (stress discontinuity, multiple corners)



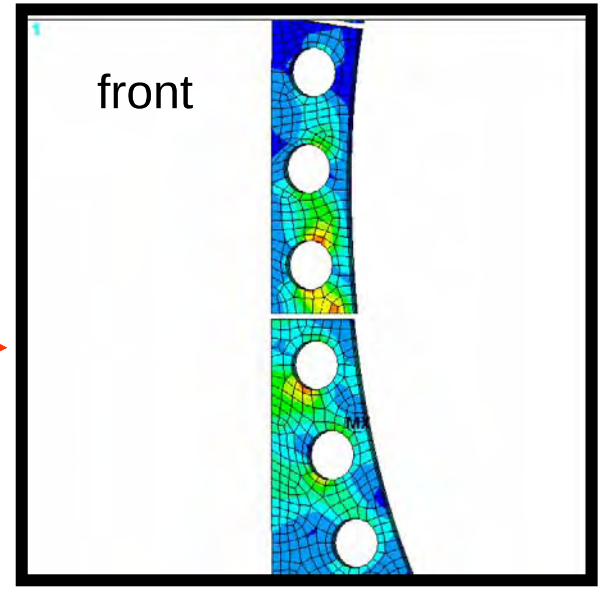
Weld and Puck Stress- (After removal of stress discontinuity elements)

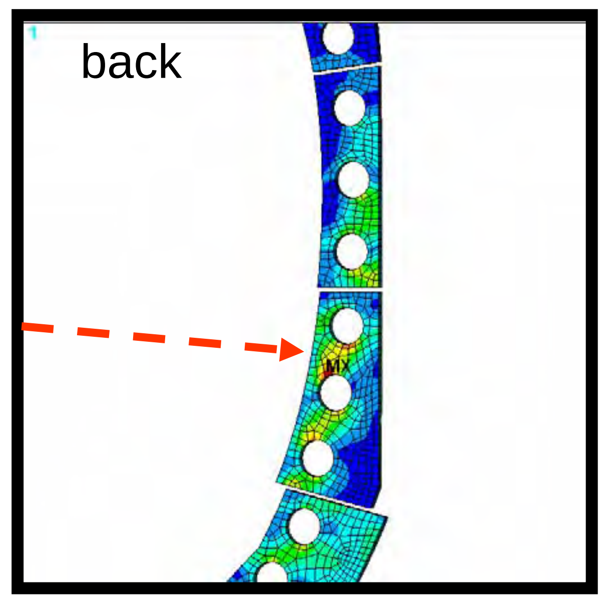


Stress in Shims



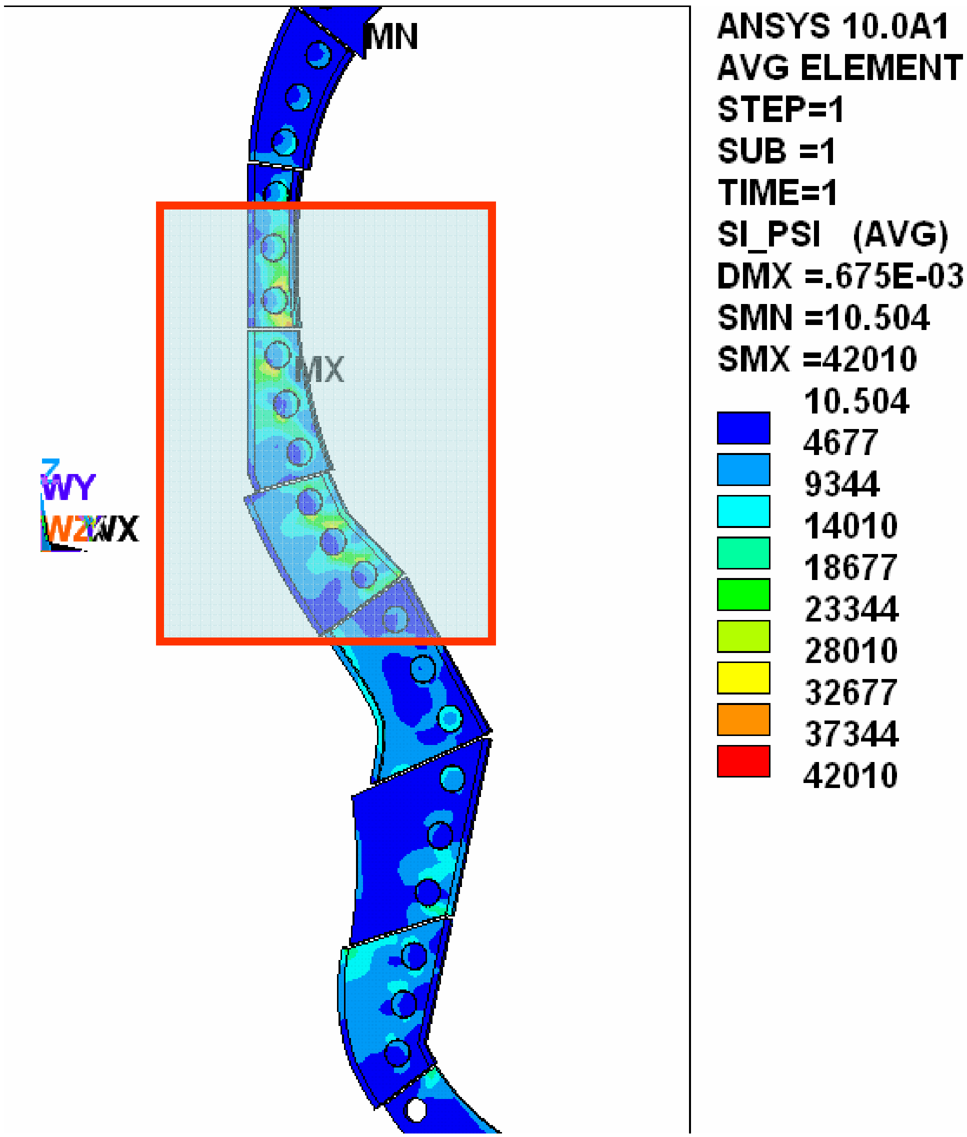
Units = psi



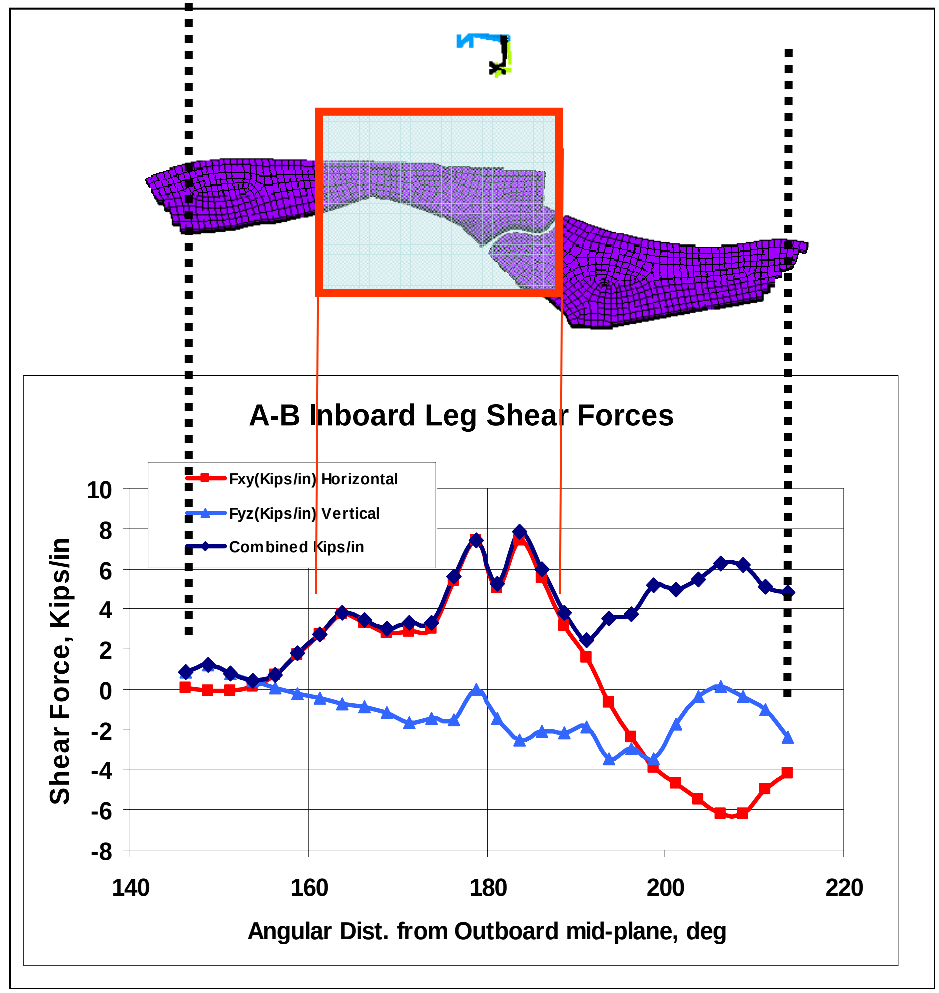


Max stress occurs on back of plate

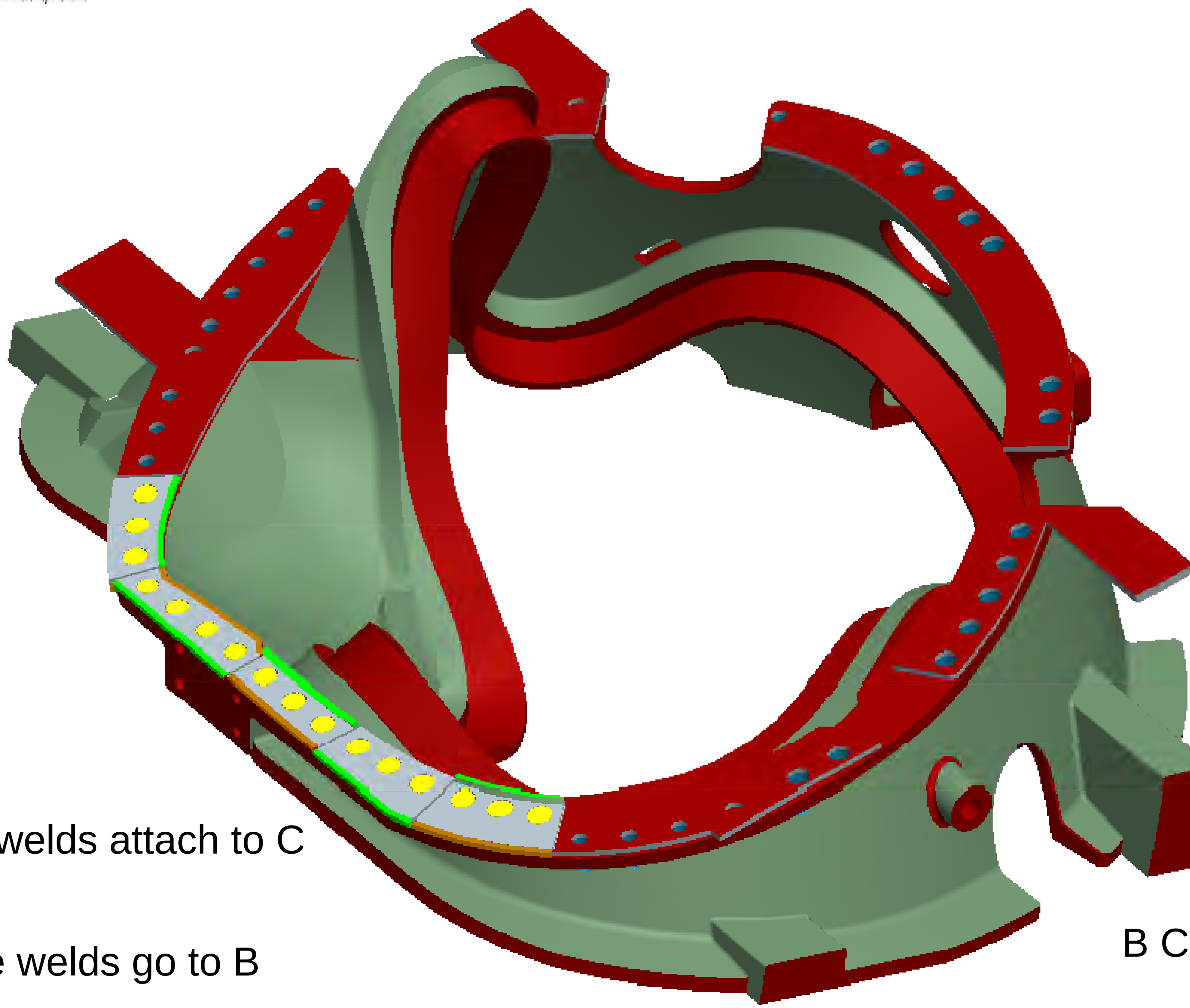
How does compare to previous results?



Peak Area of horizontal shear shown boxed in red



BC Connection

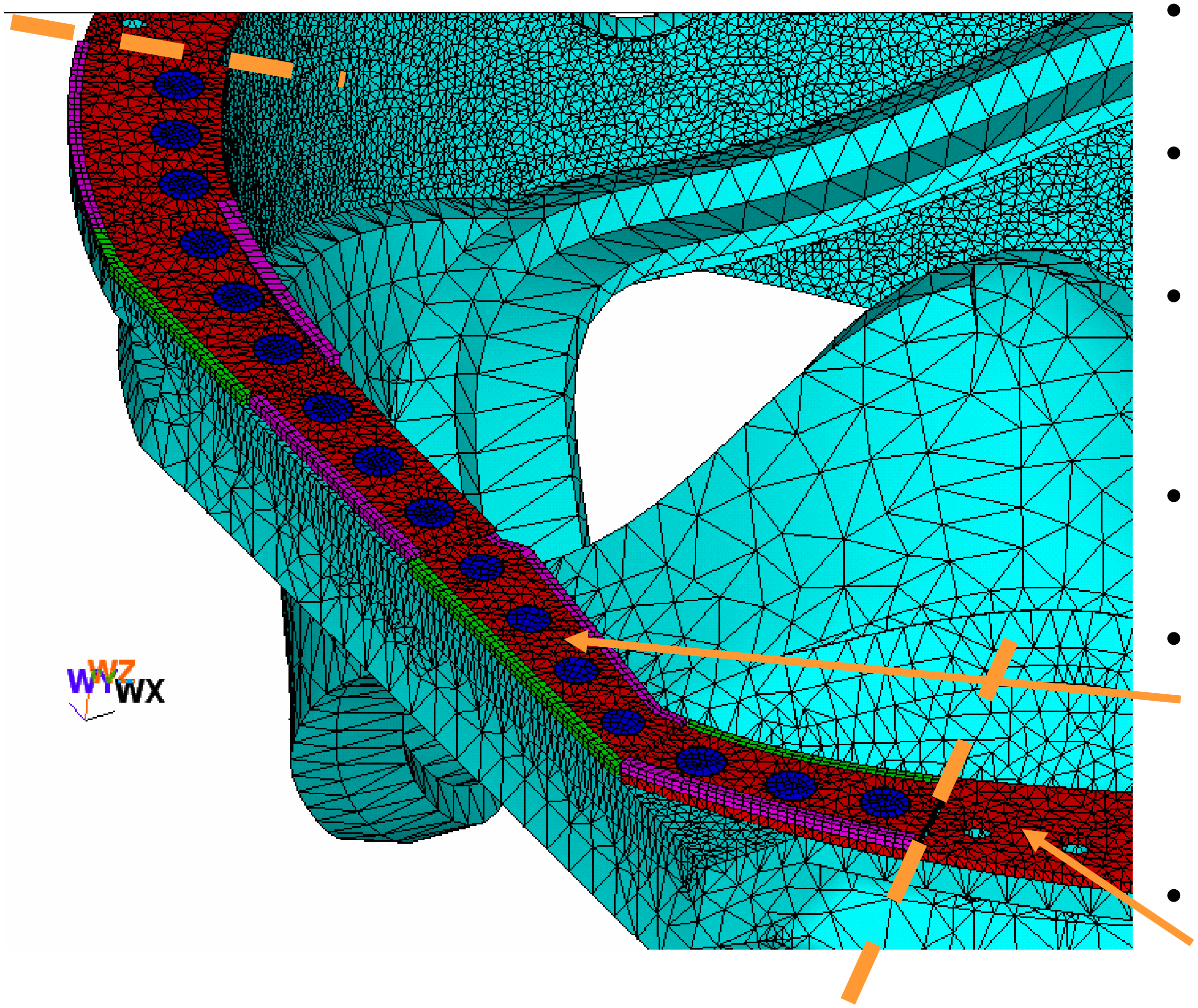


Green welds attach to C casting

Orange welds go to B casting

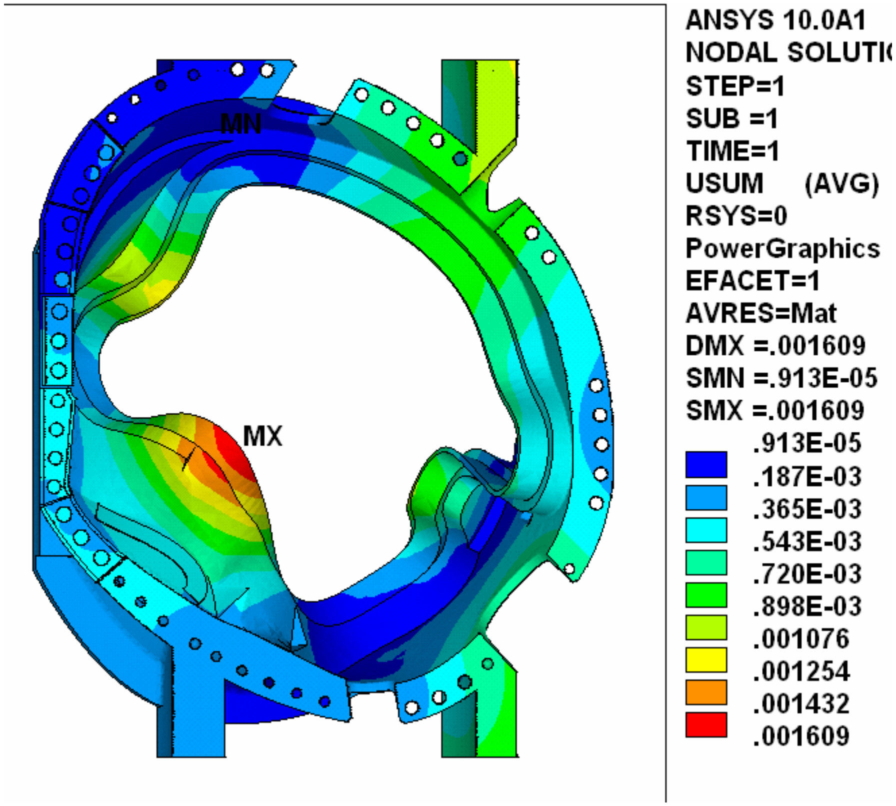
B Casting

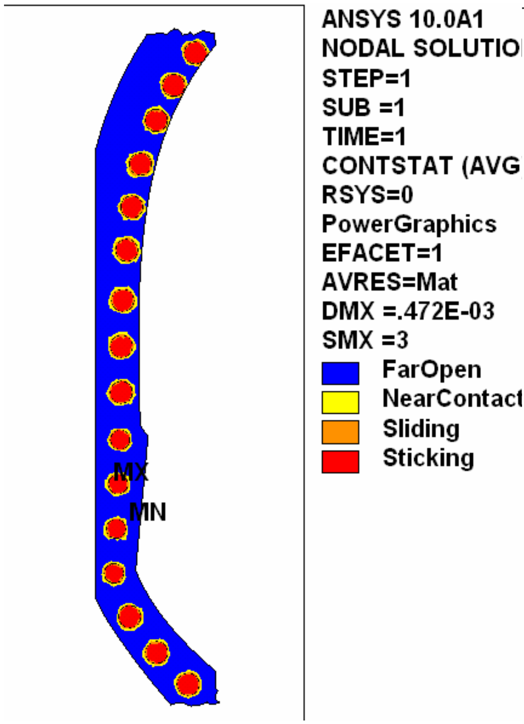
BC Analysis (same procedure as AB)

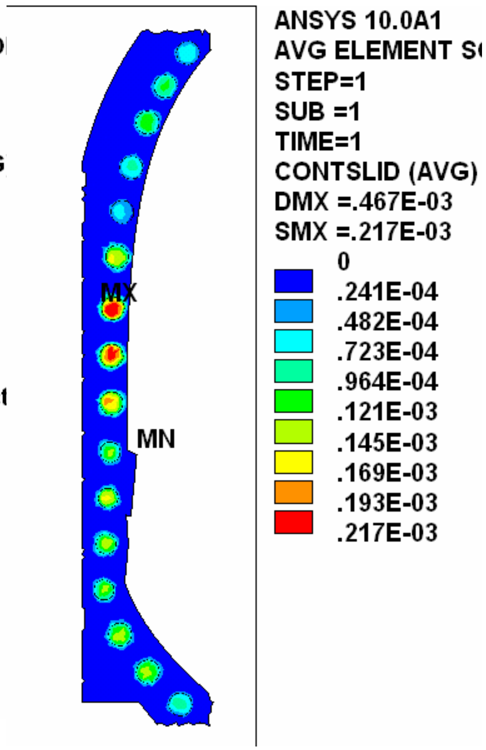


- Green welds attach to the C casting and shim only
- Pink welds attach to the B casting and shim
- Blue pucks connect are bonded to the C flange and slide on the B flange.
- Blue pucks do not interact with the red shim.
- The red shim does not interact with the casting surfaces in the region of the weld.
- The red shim is bonded to the flanges (bolt/friction) approx on the outboard areas away form the weld.

BC Deformation and puck check



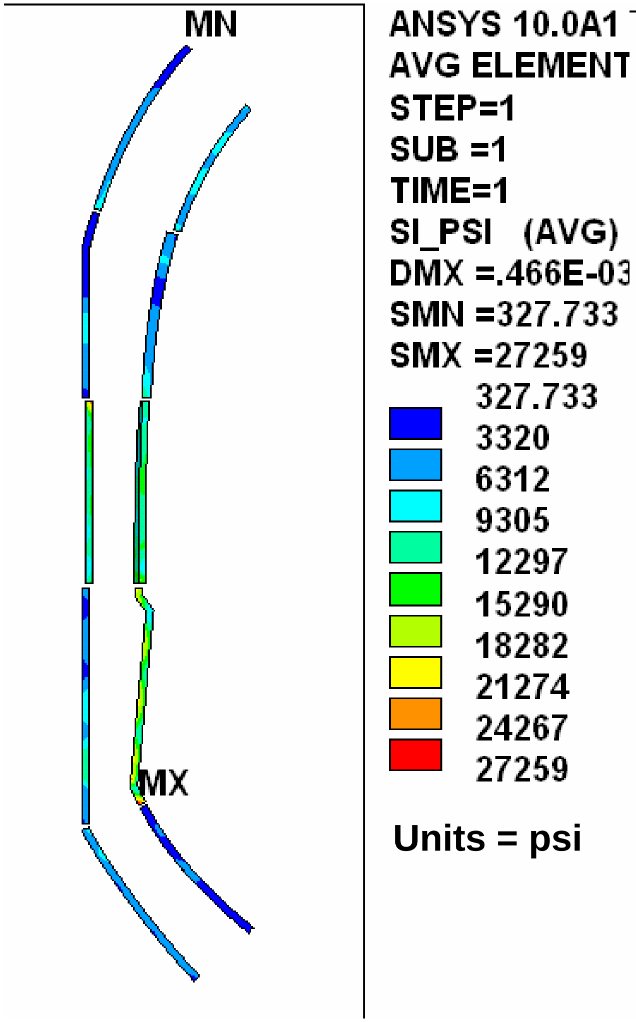




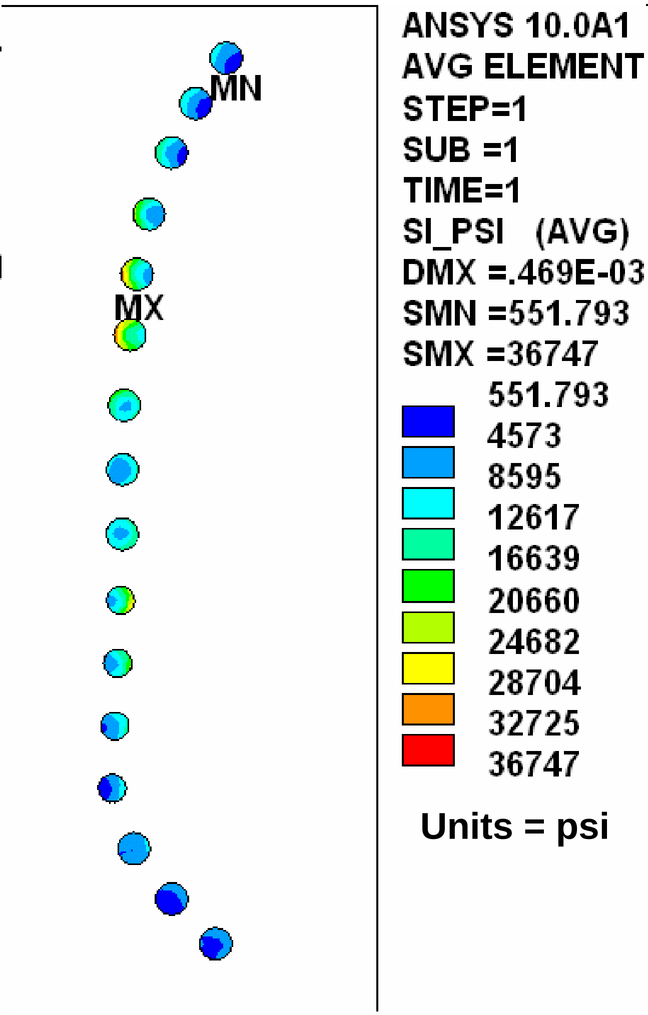
Pucks are stuck on C flange

Pucks slide on B flange (0.217 mm)

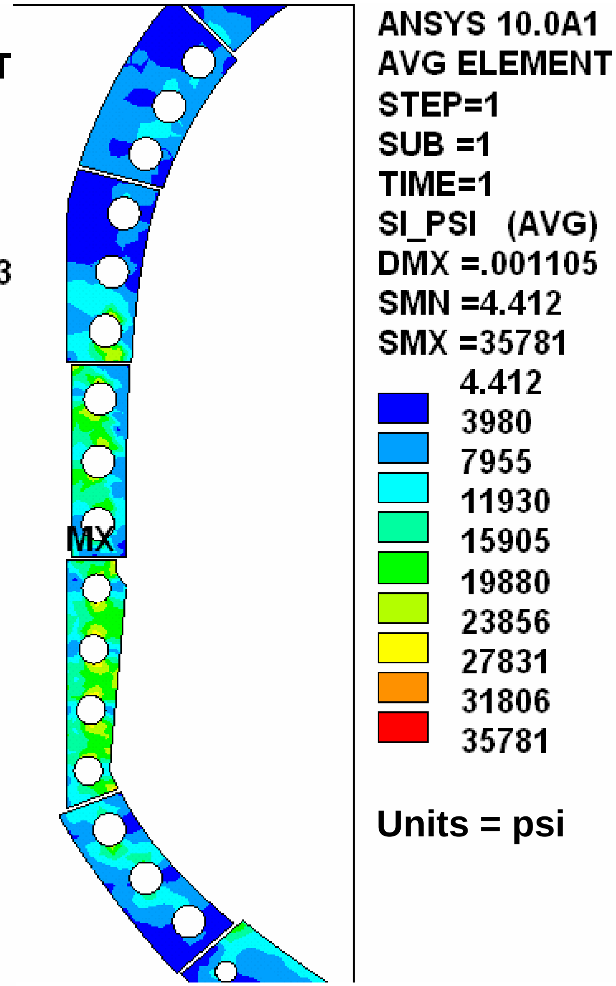
BC Stress Intensities



Welds

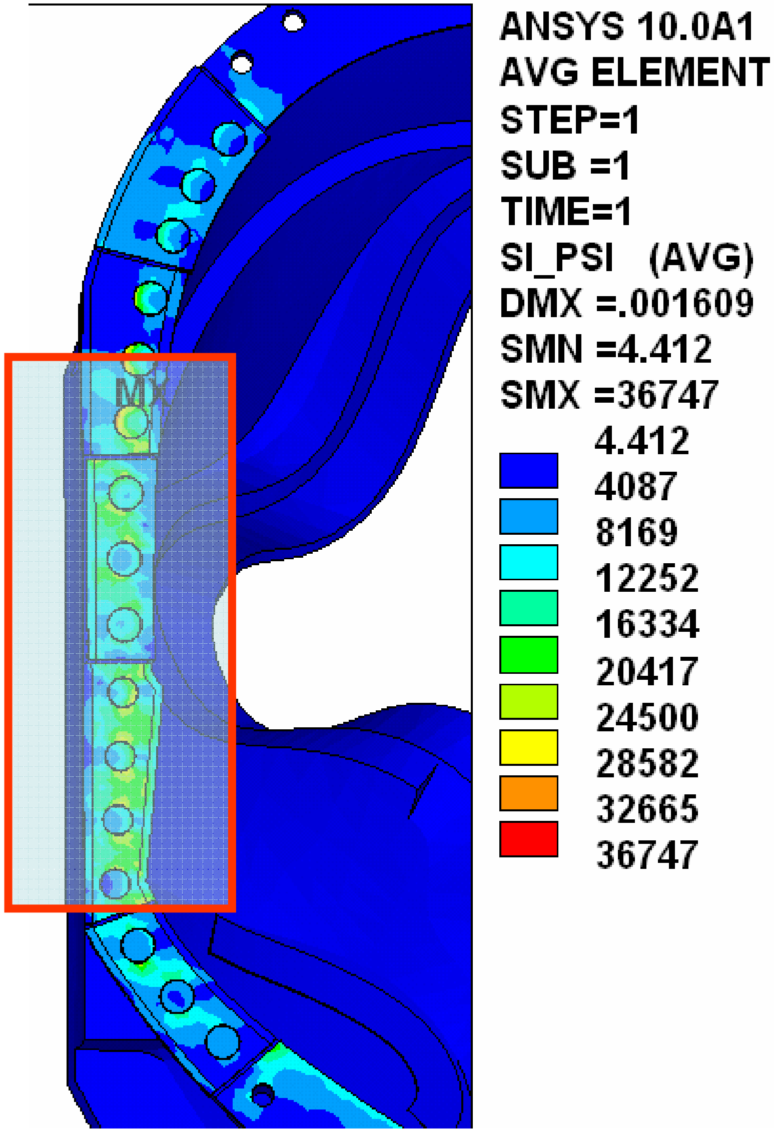


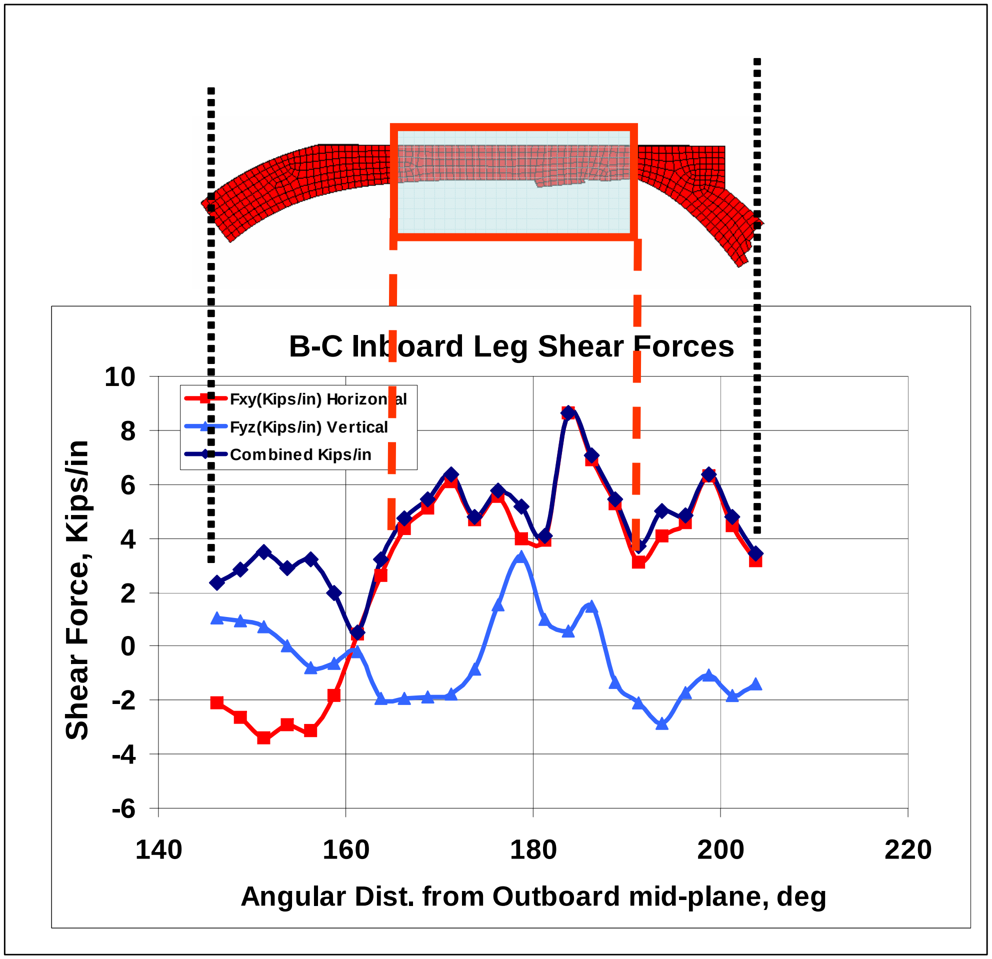
Pucks



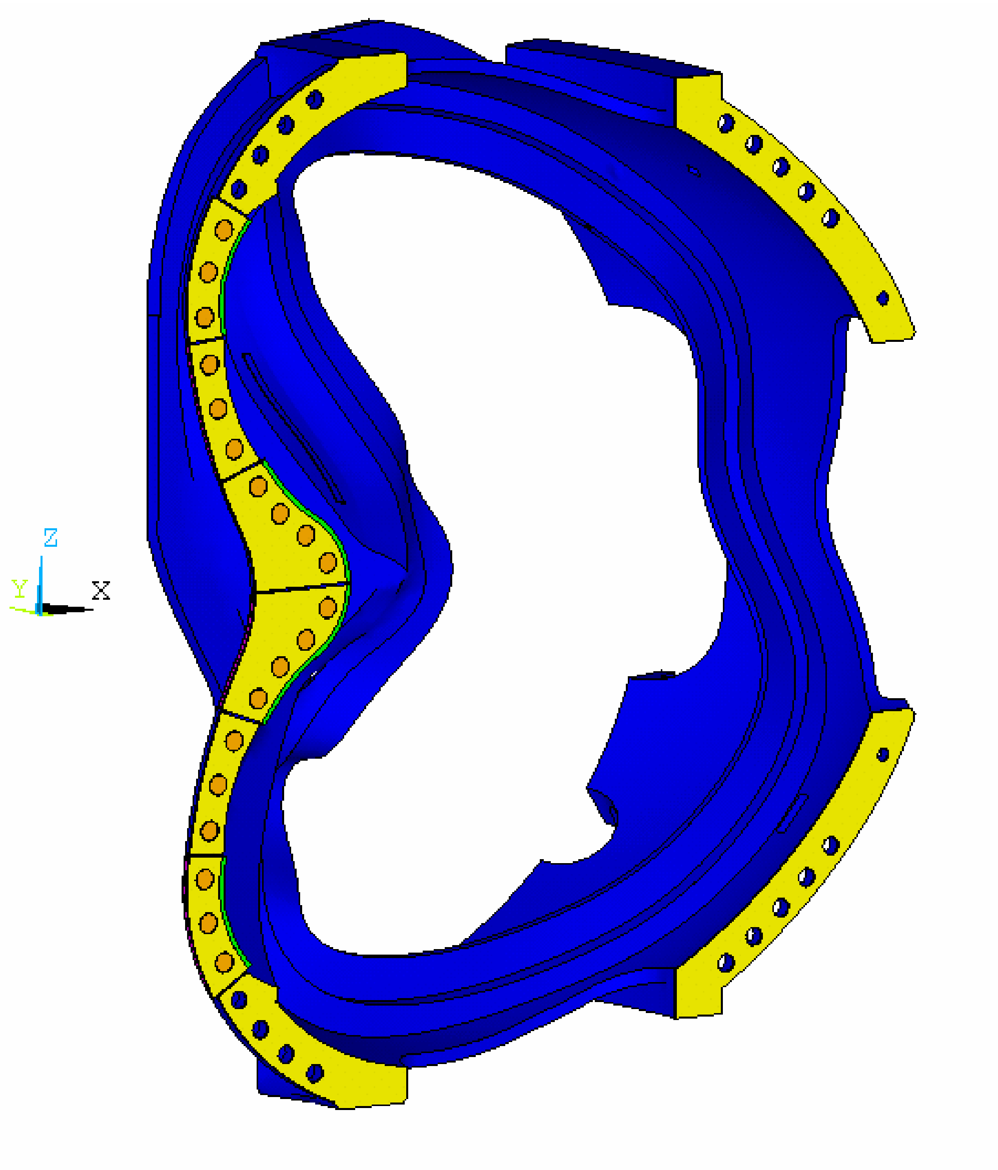
Shims

Stress Check





AA Model (special case)



Recall that the ends of the half period have anti-cyclic symmetry conditions applied to them.

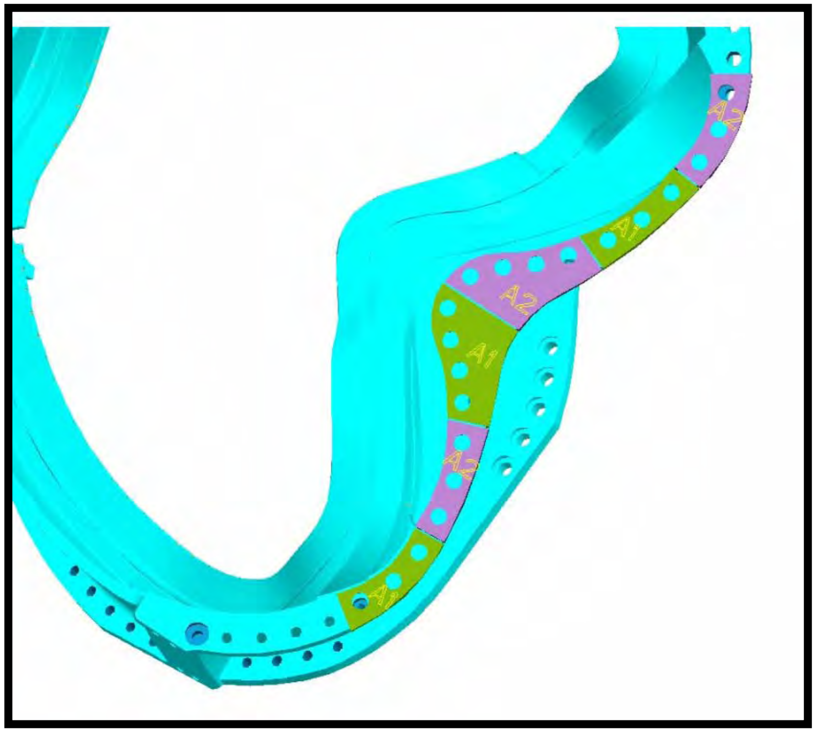
This requires constraint equations between nodes and the mesh must be identical above and below the midplane.

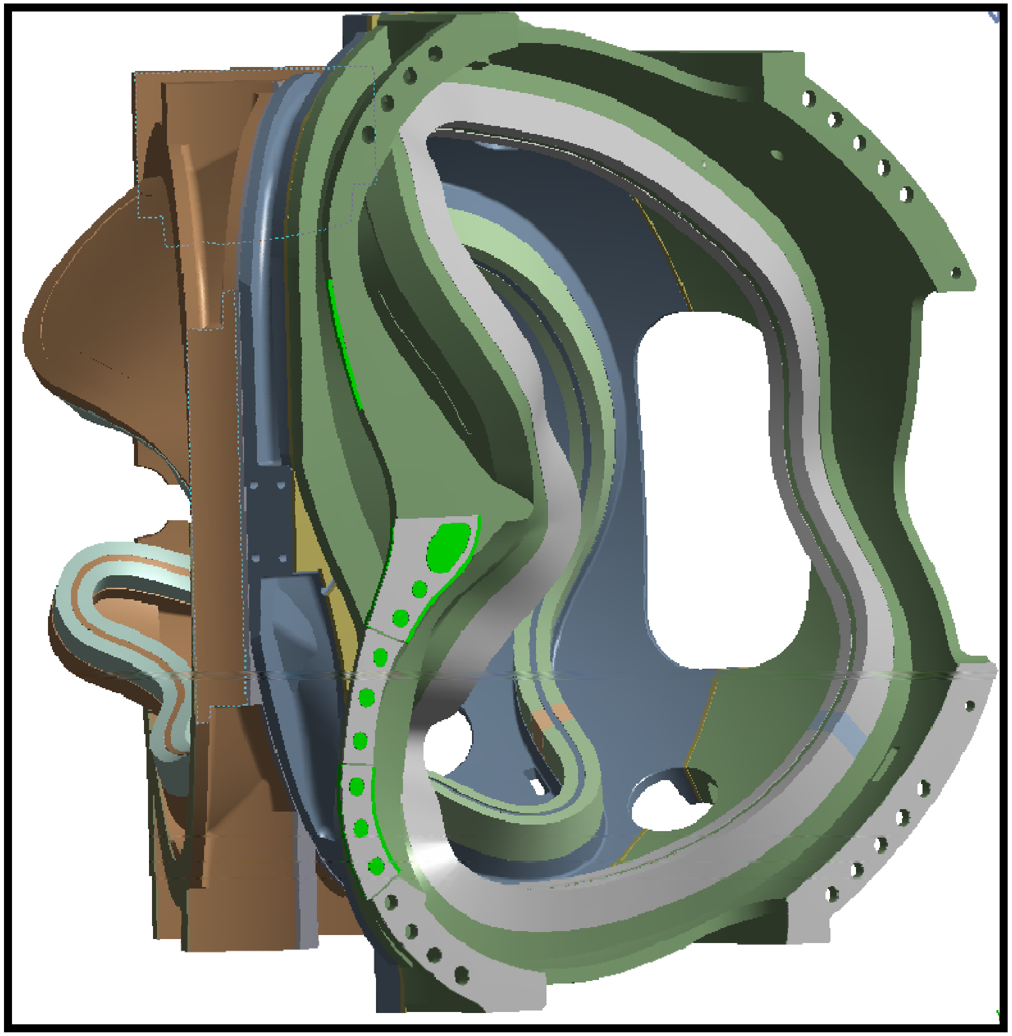
The pucks are reflected and are only connected in the y direction to their mating pair below the midplane. Thus, they are free to move in the plane of the interface and they still take the compressive load.

The welds are reflected and appropriate contact interfaces are made between the shim and flanges.

The shims are not connected to the AA flange in the region of the weld. (shear only)

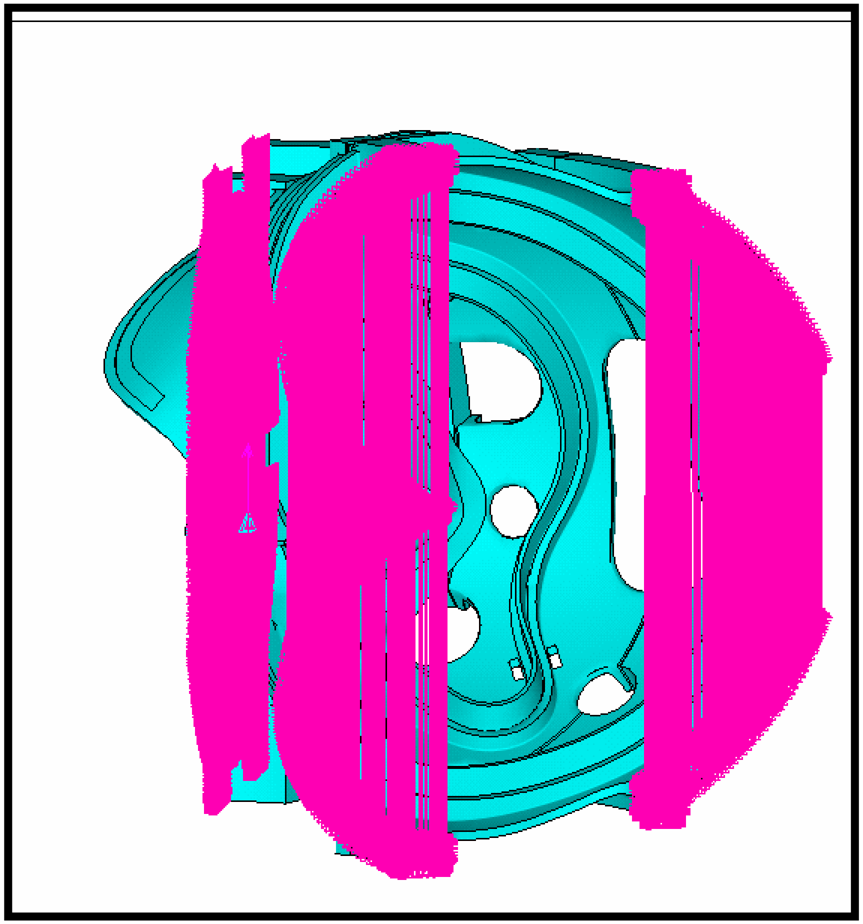
AA shim layouts

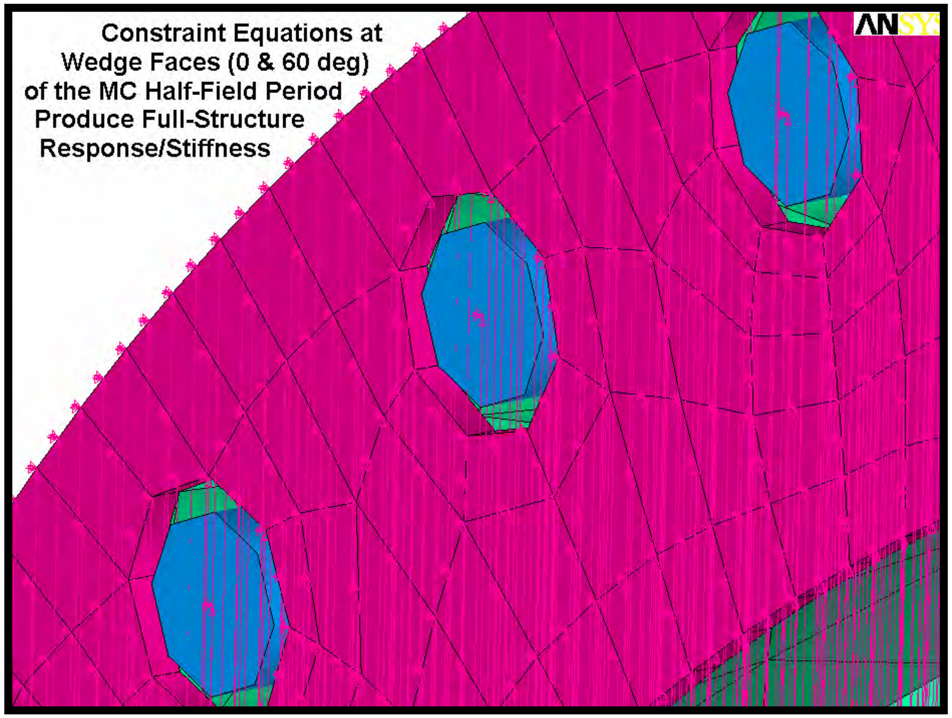




PROE model showing half shim before transfer to ANSYS and symmetry flipping of shim and welds.

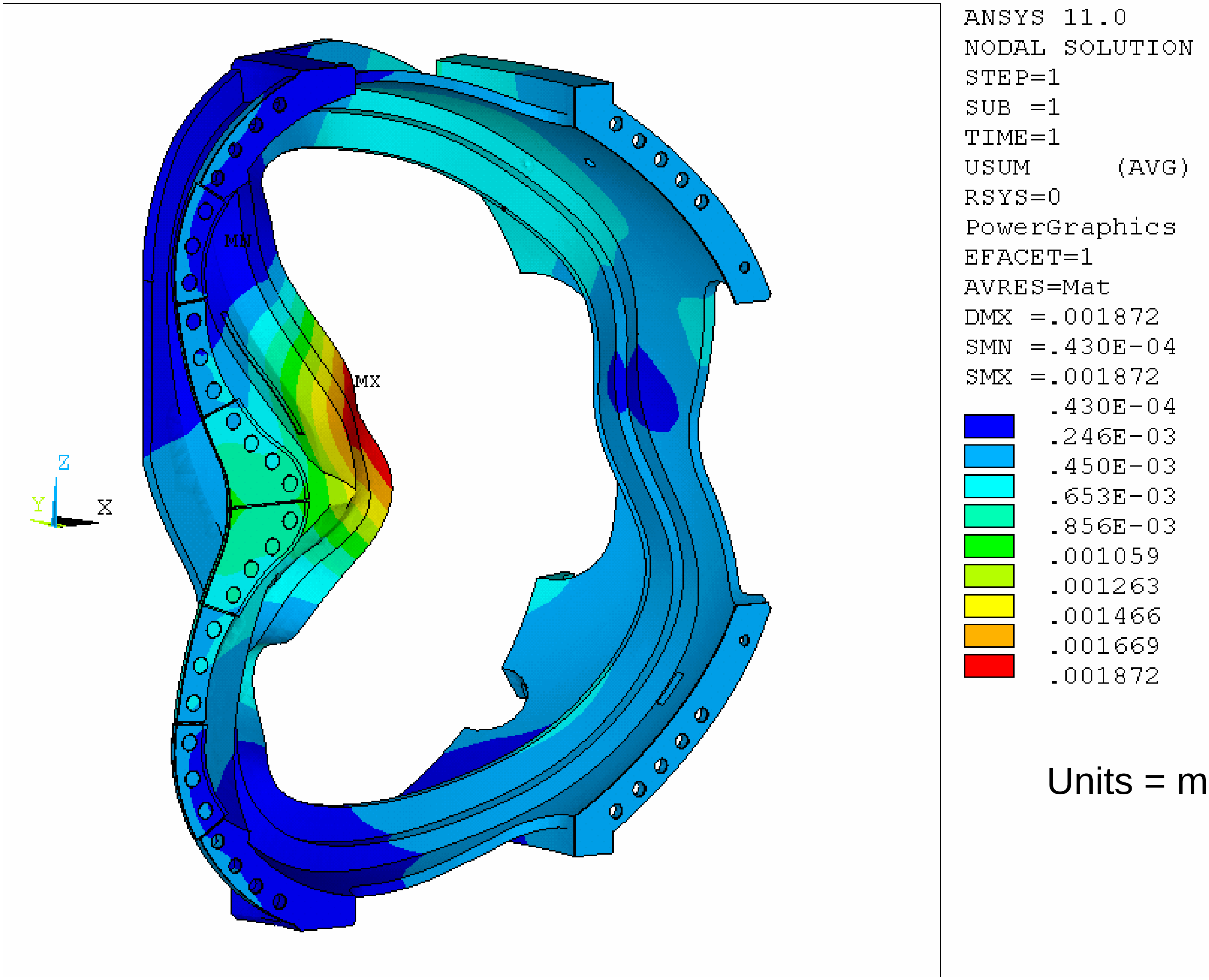
Constraint equations





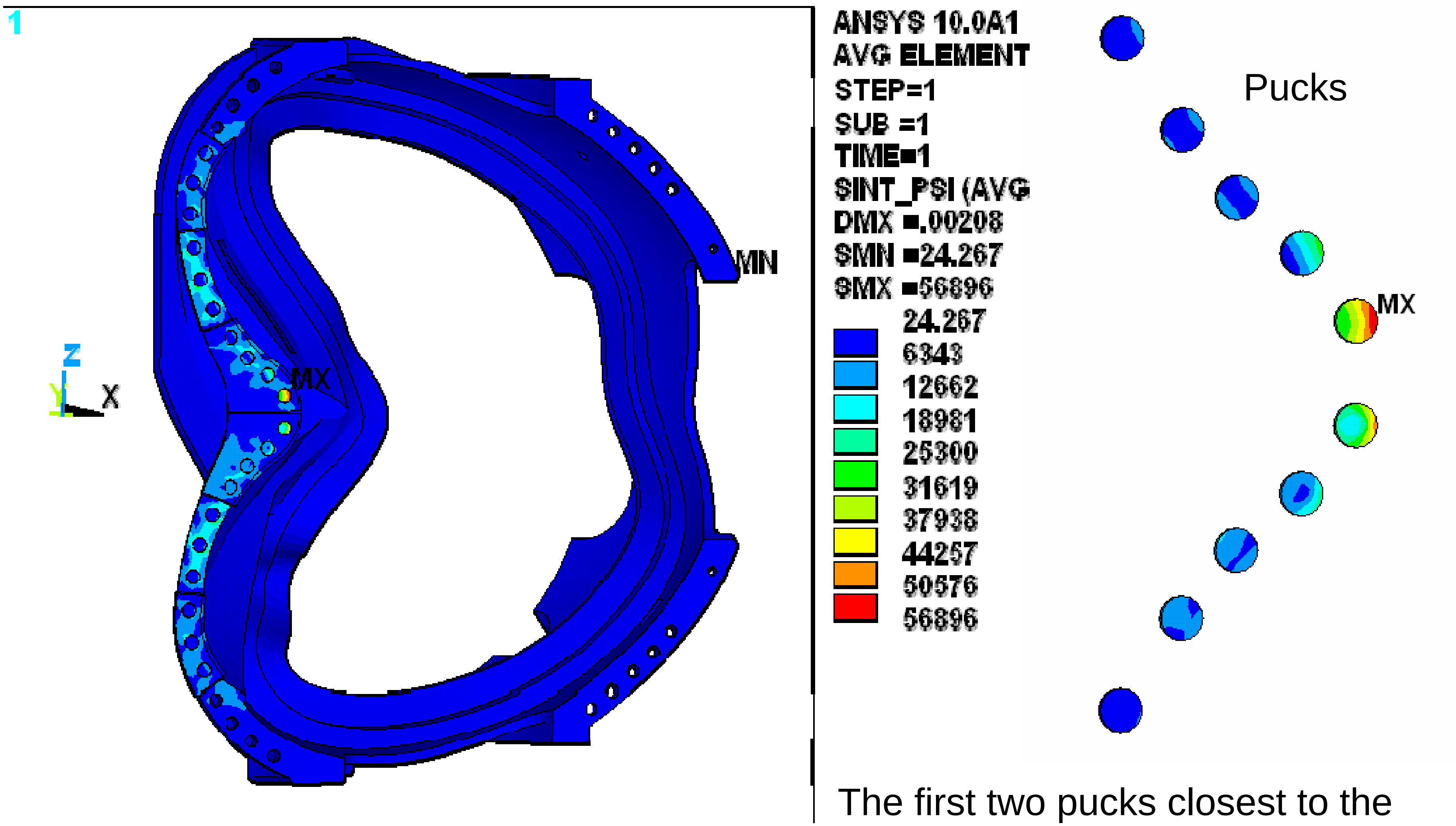
This model was used to model the bolt loads using tie elements, but procedure is the same for the welded models

Global Deflection results (meters)



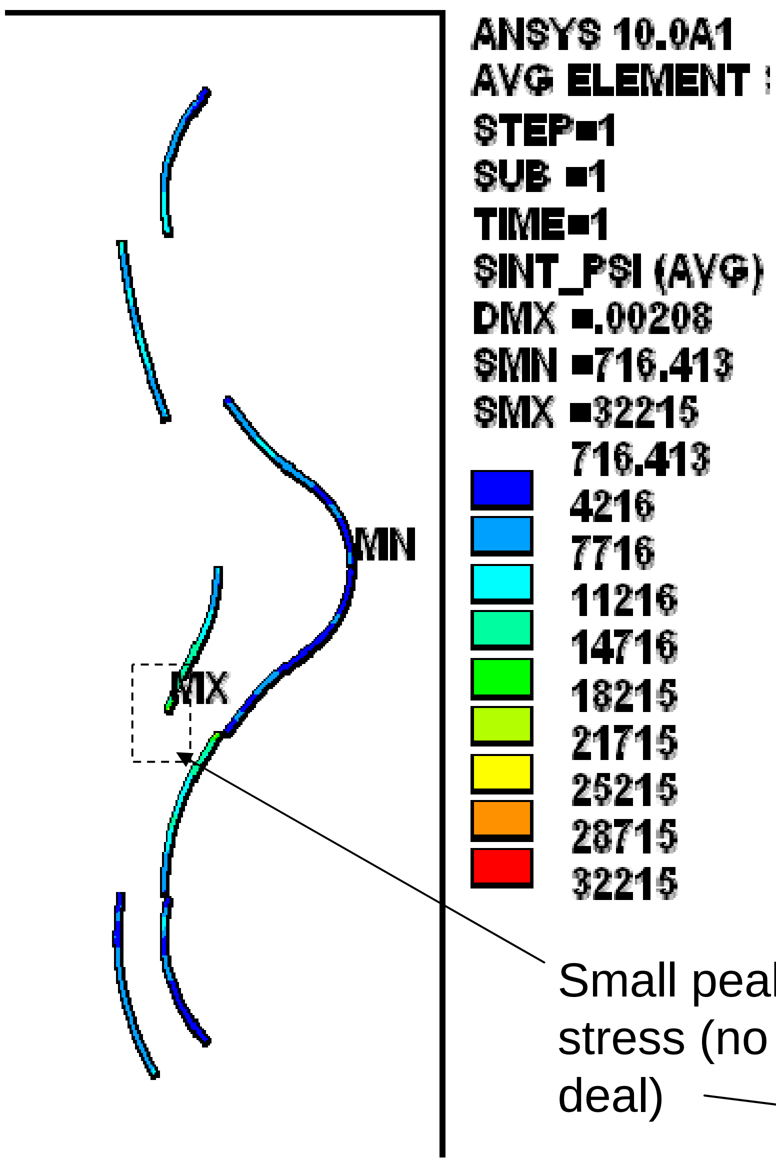
Units = meters

Stress Intensity (psi)

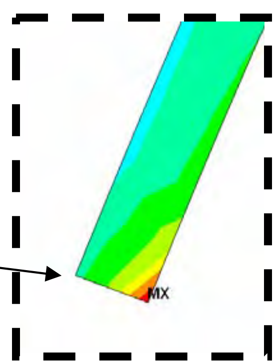


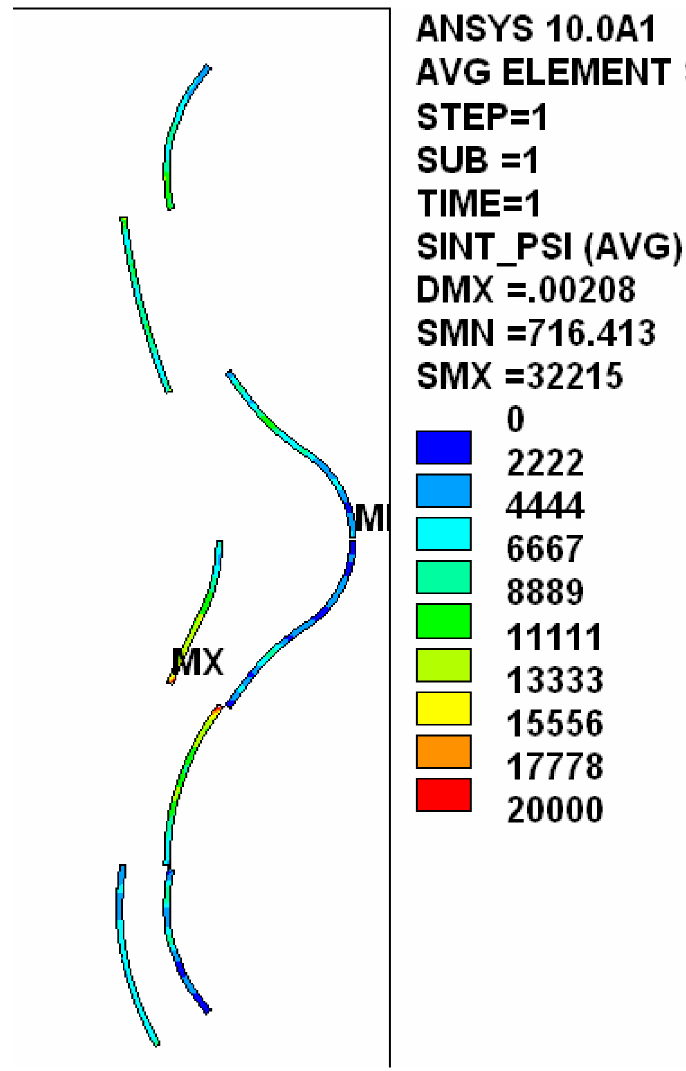
The first two pucks closest to the midplane are seeing the most compression.

Weld Stresses (psi)



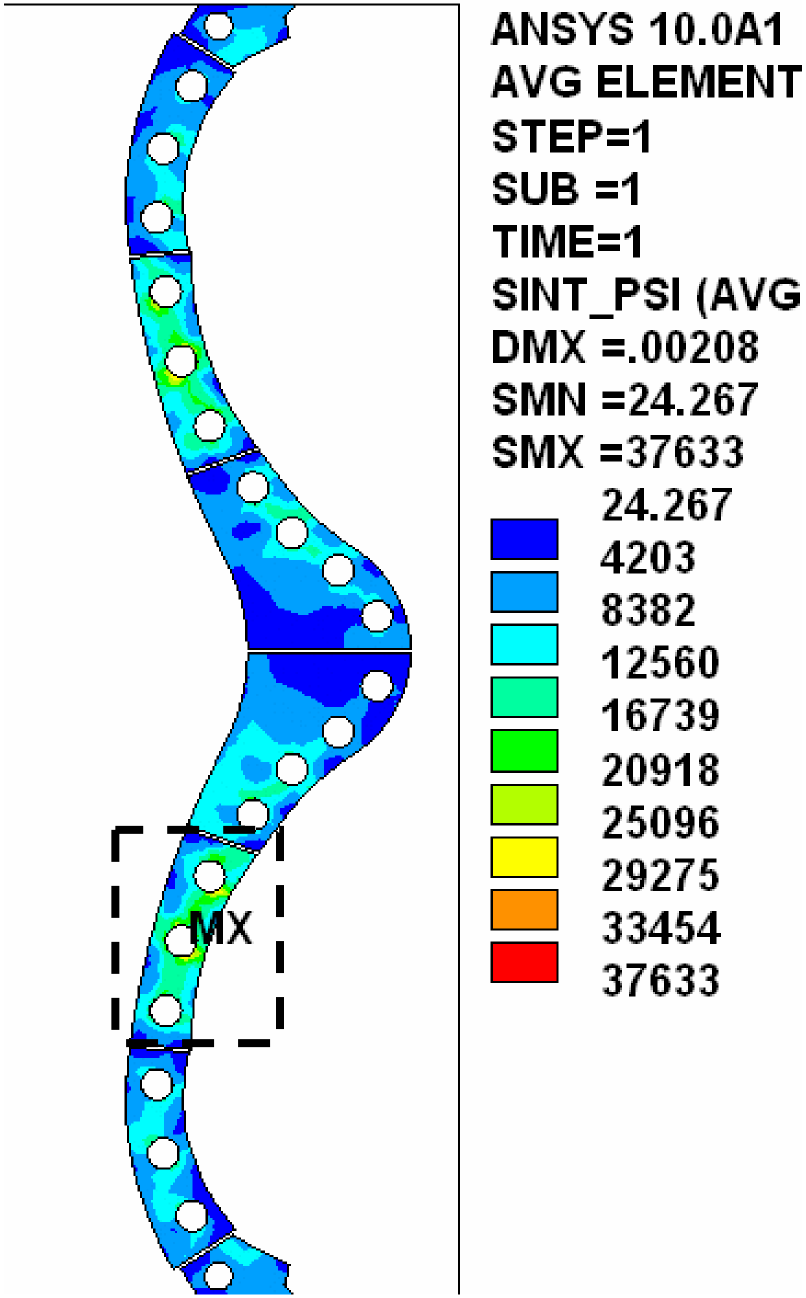
Small peaky stress (no big deal)

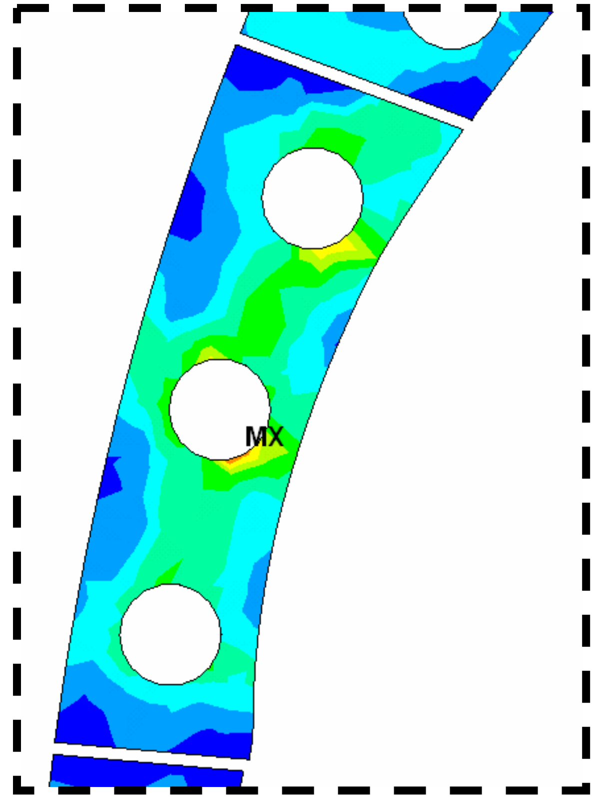




Stress Rescaled to max of 20 ksi. (very small end effects exceed this value.)

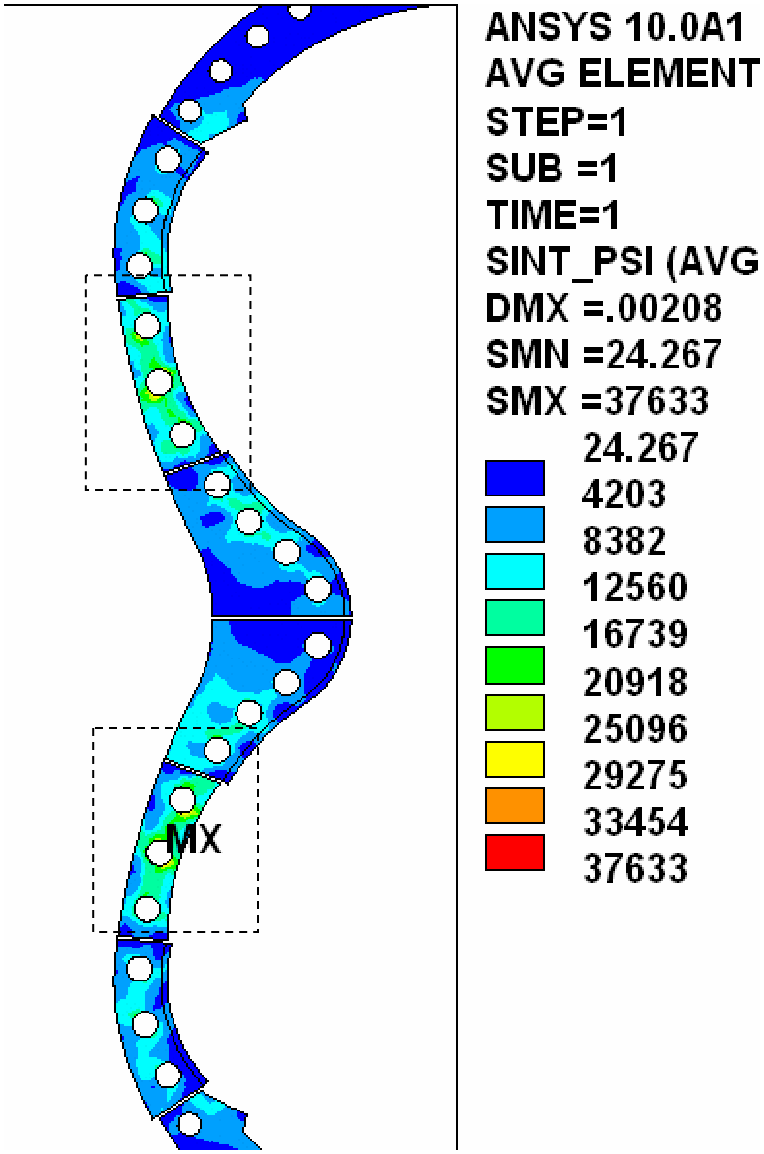
Shim Stresses (psi)

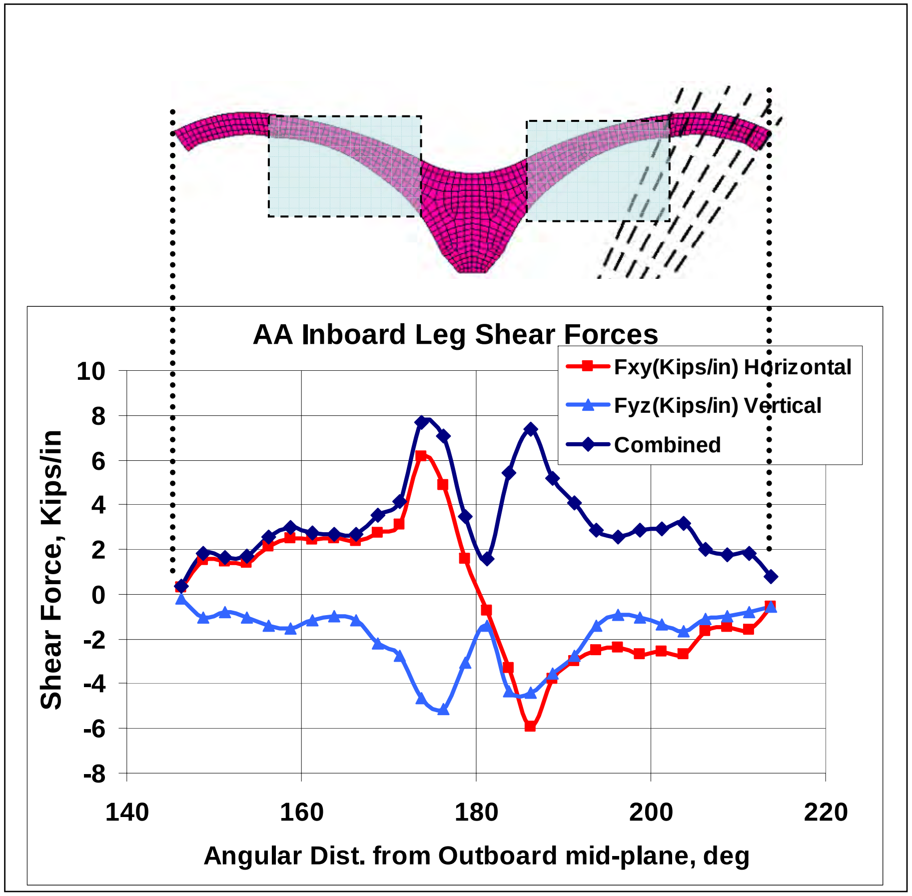




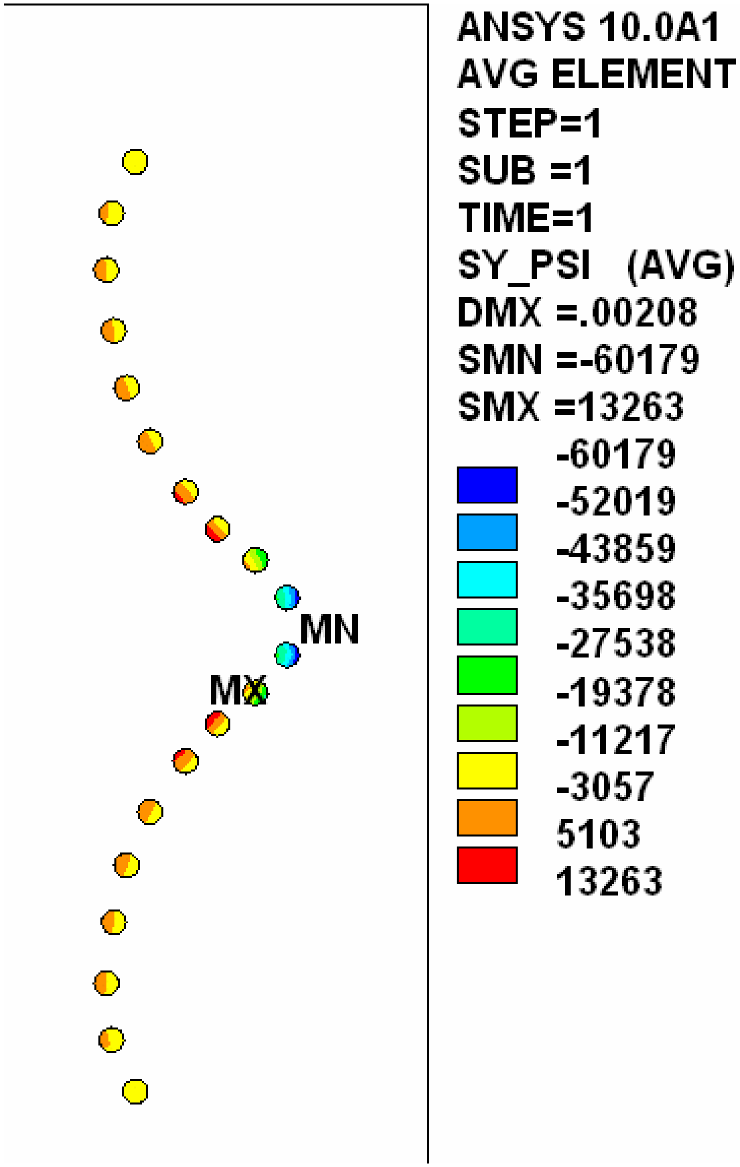
Small localized stress which can go to 1.5*Sm where Sm is 68 ksi for 316LN.

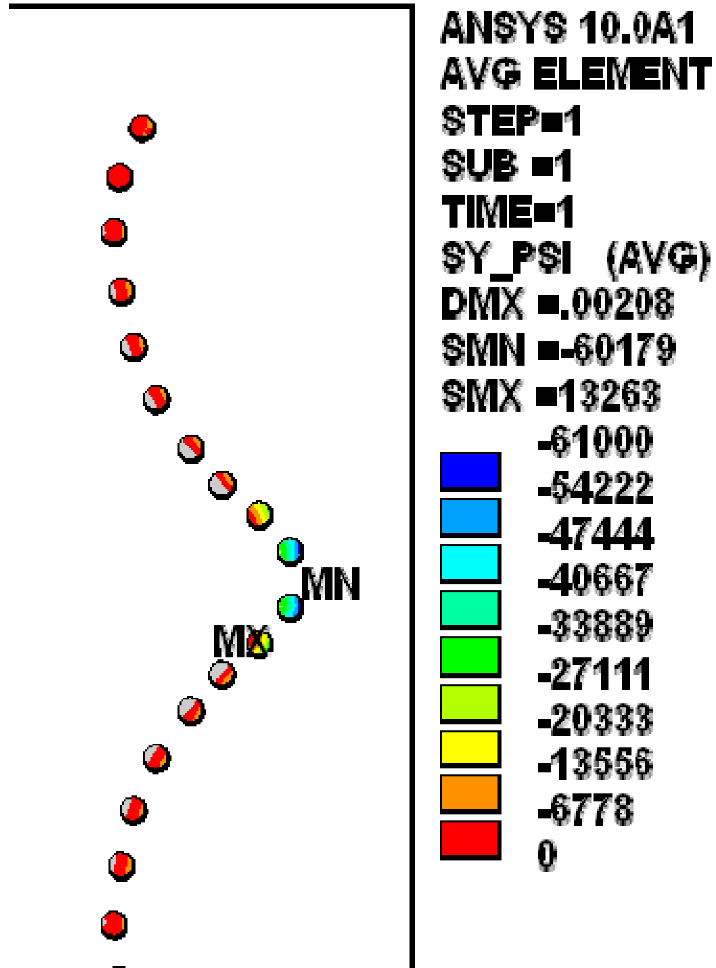
Shear check on AA





Normal Stress on Pucks (psi)

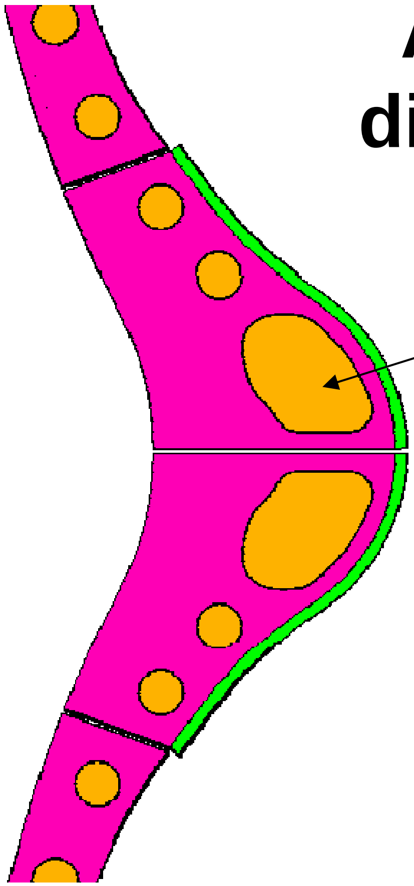


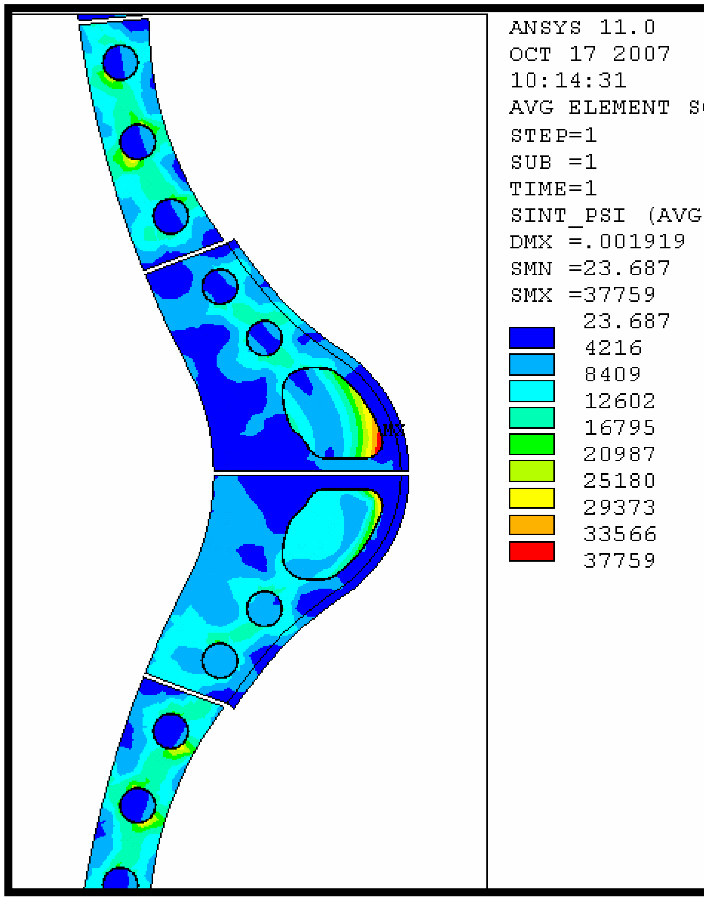


Entire puck set rescaled to min zero

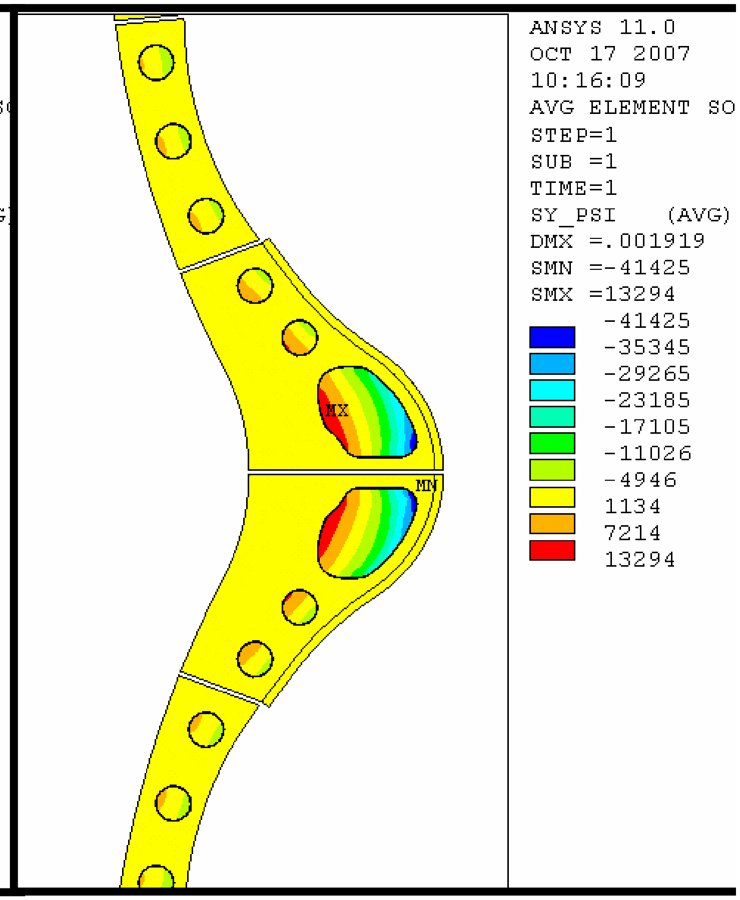
Current Solution method allows the pucks on the AA interface to carry Tension!

Amoeba Plug – An attempt to distribute the compressive load.



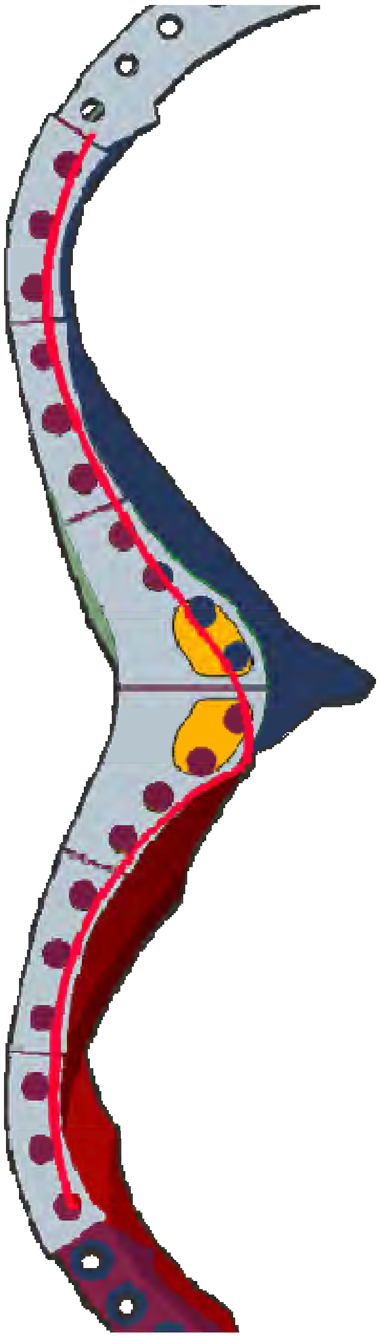


Stress Intensity (psi)



Y stress (normal to flange) psi

Compressive path



- The red Line indicates the flange to flange direct interaction zone for the pucks
- The navy blue surface is the flange surface, the red surfaces are the casting surfaces behind the flange.
- Anything to the left of the red line is on the flange and not under the shell. Most places this has little impact
- Moving the nearest midplane pucks toward the center may help distribute the compressive load.

Weld Analysis Summary Table

Flange	Peak weld stress Intensity (edges) (ksi)	Average weld stress Intensity eyeball range (ksi)	Peak Shim Stress Intensity (ksi)	Peak Puck Compressive stress (ksi)
AA	32	12-15	38	61
AB	61* (26)	15-18	42	24
BC	27	15-18	36	37

Preliminary Analysis Comments

- Peak weld stress of 61 ksi on AB is anomalous as there will be additional weld material immediately near it. It is extremely peaky and likely due to sharp geometric cornering.
- Average stresses across weld when not considering those regions are approximately 15-20 ksi.
- Global Fea Model is currently non-conservative in that it does not include weld segmentation of 4” in with 0.25” gaps. Currently, all welds are continuous. (Small effect anticipated as seen with previous sub-models of older NCSX designs)
- Global Fea Model is currently non-conservative in that it does not model the weld as a fillet weld and instead uses the easier to construct square type welds. MIG welds actually resemble more square shape than triangular anyway. (Small effect anticipated as seen with previous sub-models of older NCSX designs)
- AA weld analysis is conservative in that the pucks in the model currently carry tension. Peak compressive stress will be lower than shown.
- The global Model has shown that a 0.5” fillet welds (0.35” throat) are adequate as modeled to support the shear loads on the AA, AB and BC flanges.
- Quick check FEA model verifies a small effect on the smaller weld size [0.44” (0.31” throat)] and shape.

Chits Status

- Peer review of inboard welded shims conducted on May-18
- No chits submitted, but weld distortion identified as main risk
- Actions planned at that time:
  - Shim layout
  - Structural analysis of welds
  - Access for welding
  - Development of weld procedure
  - Material selection
  - Deformation control options

Plan to complete final design

NCSX National Compact Stellarator Experiment

Task	Description	Proposed	Scheduled
INTRF-040	Analysis of tensile loads (ORNL)	18-Oct-07	15-Aug-07
INTRF-064	PDR	18-Oct-07	18-Oct-07
INTRF-054	FDR prep AB/BC/AA inboard Interface	19-Oct-07	4-Sep-07
INTRF-055	AB/BC/AA inboard interface - FDR	22-Nov-07	4-Sep-07
1421-3138	Resolve issues, release assembly spec&drawings	23-Nov-07	11-Sep-07
* 1429-3069X	Inboard Shims Available for 1st 3 pack MC assy	11-Dec-07	

* Note: Task 1429-3069X - We will initiate a risk release after the PDR to start fabrication of the inboard shims. Material for fabricating the shims is in the process of being ordered.

Conclusion

- Are the requirements defined? What is the proposed design?
  Requirements are defined. Design is documented and drawings have been developed.

- What is the status of welding trials?
  Welding trial samples are have been completed. The type C prototype longitudinal weld test is underway. Welding procedure and welder qualifications will be formalized prior to performing assembly welds.

- Is the analysis consistent with proposed design?
  Analysis updated- AA, AB, BC welds are adequate

- Have prior design review chits been addressed?
  Peer review identified development activities- underway

- Have all technical, cost, schedule, and safety risks been addressed?