Design of Close-Fitting Coils and Structure

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NCSX Project Meeting
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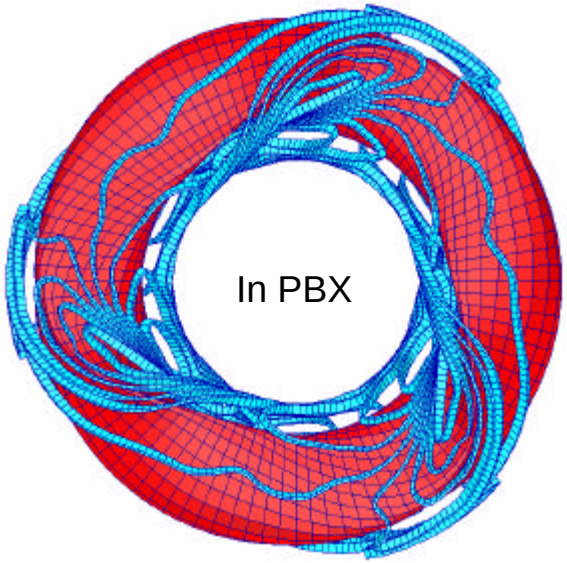
Progress Since Last Meeting

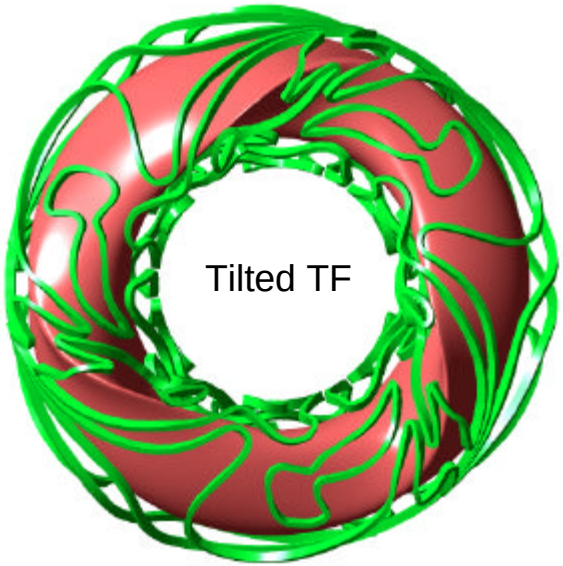
- Update of Cost Estimate Spreadsheet for In-PBX Option Conformal Coils
- Evaluation of Conformal Coil Options:
  - Tilted TF Coil Option - Case 536
    - Winding Configuration
    - Shell Segmentation Options
  - L=3 Option - Case 619
    - Winding Configuration
    - Conductor Issues
  - Modular Coil Option - Case 0424
    - Winding Configuration
    - Structural Concepts
    - Coil-to-Coil Interference
    - Fabrication / Assembly
    - Access Issues

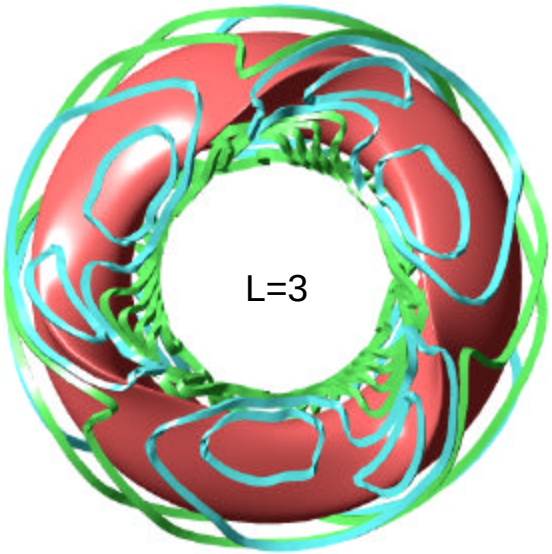
Description of Conformal Coil Options for C82 Plasma Configuration

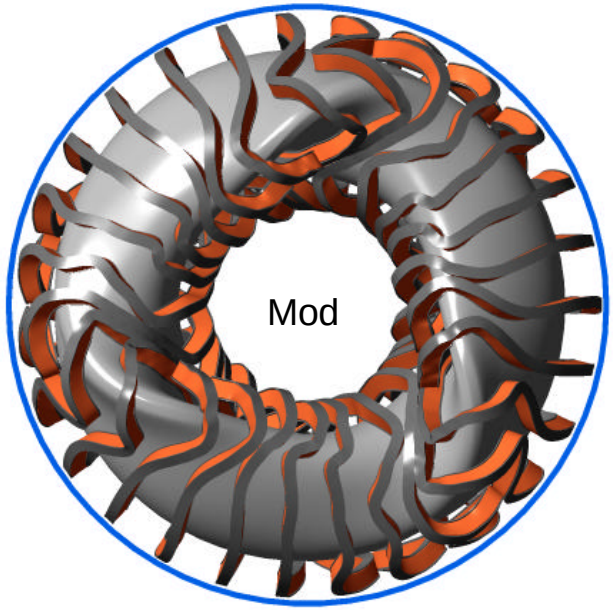
Option	In-PBX	Tilted TF	Titled TF	L=3	L=3	Modular
Coil Set	4064	536	536	691	691	0424
No. Saddle Coils	30	30	30	36	36	0
No. Unique Saddles	5	5	5	6	6	0
No. Wavy PF Coils	0	5	5	8	8	0
No. Unique Wavy PF	0	3	2	4	4	0
No. Modular Coils	0	0	0	0	0	27
No. Unique Coils	0	0	0	0	0	5
Current at 2-T, kA	115-184	179	179	215	215	529
Min Coil Spacing, cm	2.3	5.2	5.2	5.3	5.3	
Nom. Width, mm	16-22	42	42	51	51	90
Nom. Height, mm	70	70	70	70	70	160
Coil Length, m	1.8-16	0.7-7.3	0.7-7.3	0.6-14.8	0.6-14.8	
Total Length, m	214	102	102	168	168	
No. Turns	10	18	20	22	24	28
Cur Density, kA/cm2	~27	11.9	13.3	12.1	13.0	10.9
Cooling Scheme	Cond to Shell at -200C	Cond to Shell at 20C	Internal Flow at 20C	Cond to Shell at 20C	Internal Flow at 20C	Internal Flow at 20C
Temp Rise, deg-C	~200	87	112	90	106	71
Cool-Down Time, min	< 5					
Flow Parameters	N/A	N/A		N/A		
Support Structure	Bronze Shell	Bronze Shell	Bronze Shell	Bronze Shell	Bronze Shell	TBD
Max Load, lb/in	1960					
Thk Parameter, mm	7.7	8.8	8.8	9.6	9.6	N/A
Eng/Des Cost, $k	1245					
R&D Cost, $k	986					
Fab/Proc Cost, $k	2640					
Asm/Inst Cost, $k	2001					
Contingency, $k	2062					
Total Cost, $k	8934					

Description of Conformal Coil Options for C82 Plasma Configuration

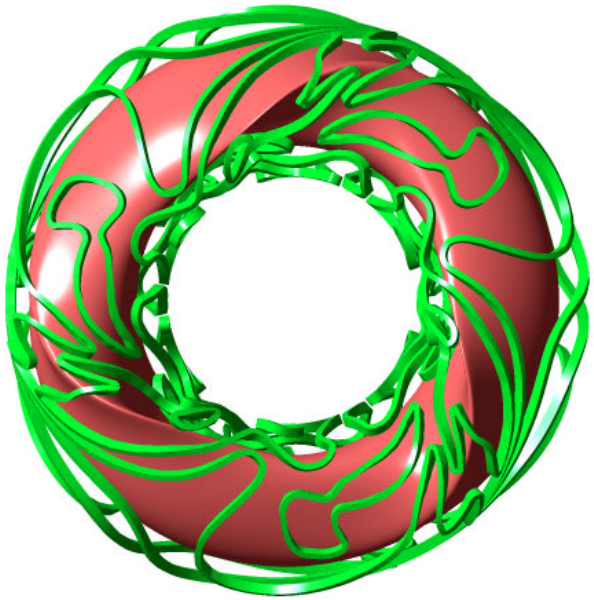


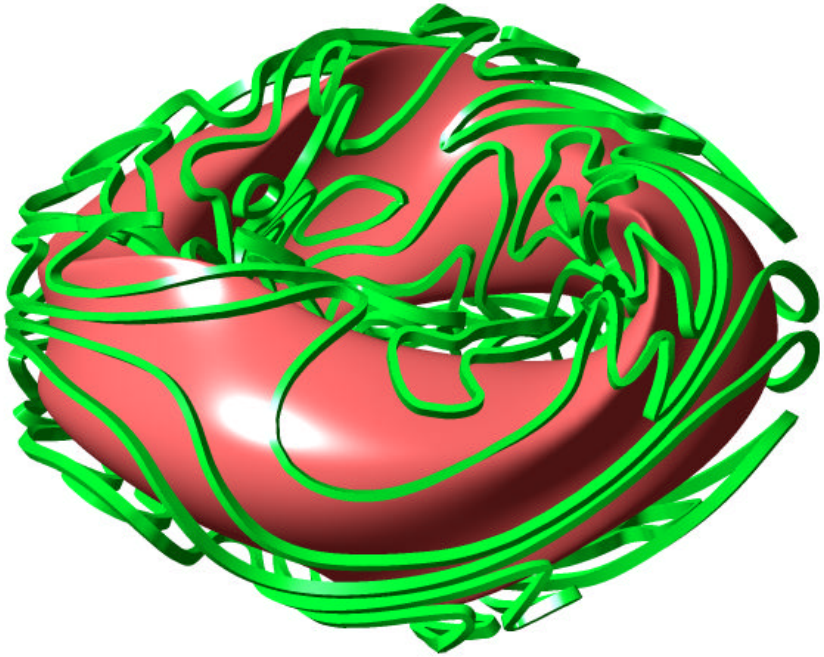


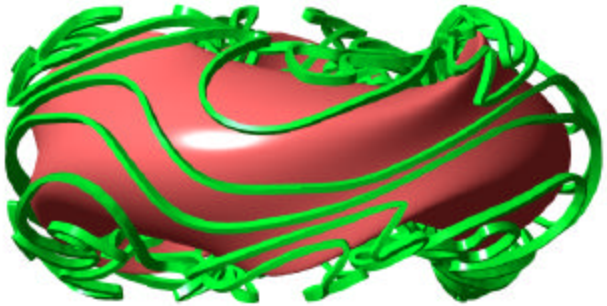




Tilted TF Coil Option, Case 536 Conformal Coil Arrangement

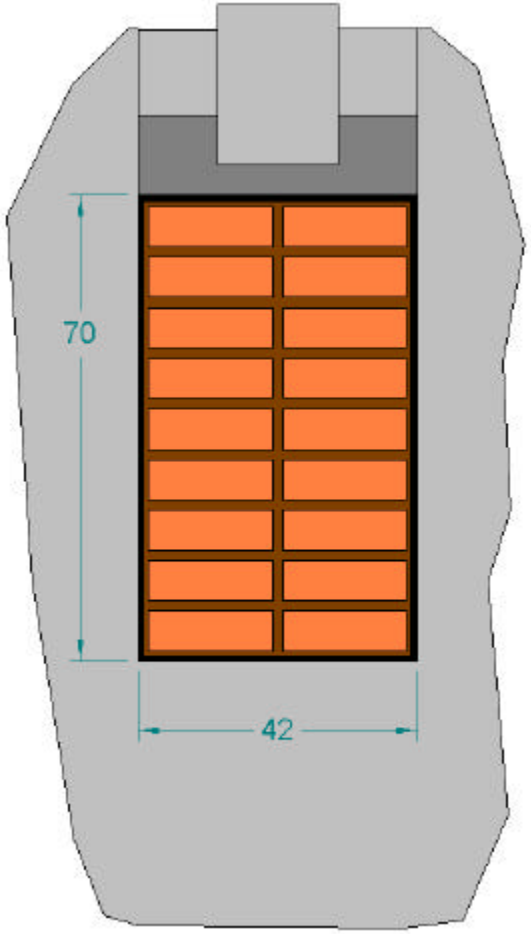




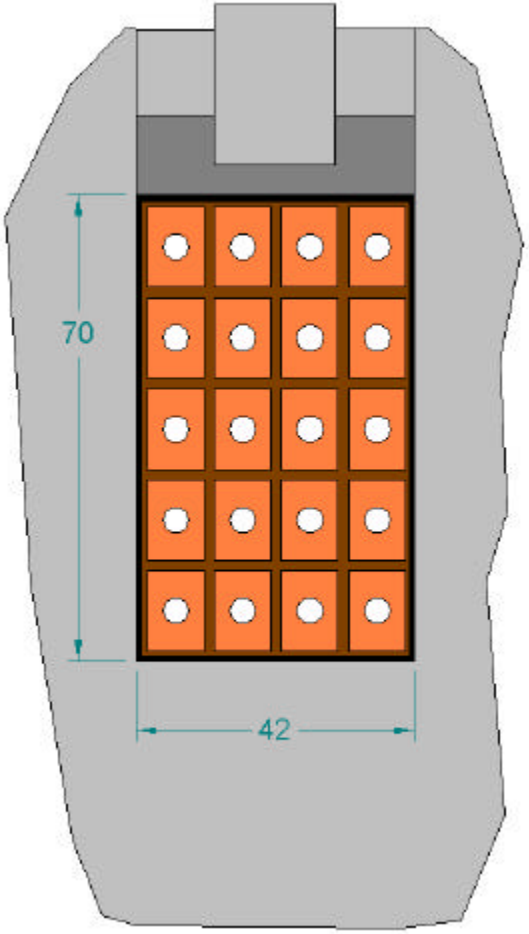


- 8 Unique Coils, 35 Total
- 179-kA per Coil at 2-T
- 4.2x7-cm Nominal Dims

Tilted TF Coil Option, Case 536 Conformal Coil Winding Configurations



Cabled conductor, 18.6 x 6.0-mm
Packing factor = 0.75
No. Turns / coil = 18
Current / turn = 10.0-kA
Current density = 11.9-kA/cm2



Cabled conductor, 8.5 x 12.1-mm
Packing factor = 0.75
No. Turns / coil = 20
Current / turn = 9.0-kA
Current density = 13.3-kA/cm2

Tilted TF Coil Option, Case 536 Structural Shell Segmentation

Motivation:

- Case 536 has distinct coil groups:
  1) inboard wavy PF
  2) saddle coils
  3) outboard wavy PF

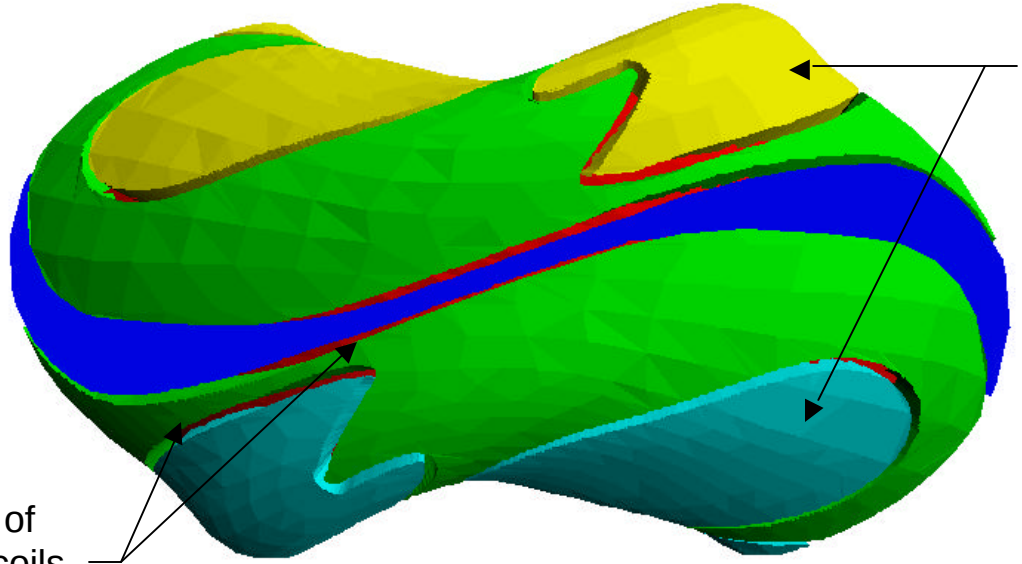
- Separate shell subassembly for each group may be possible

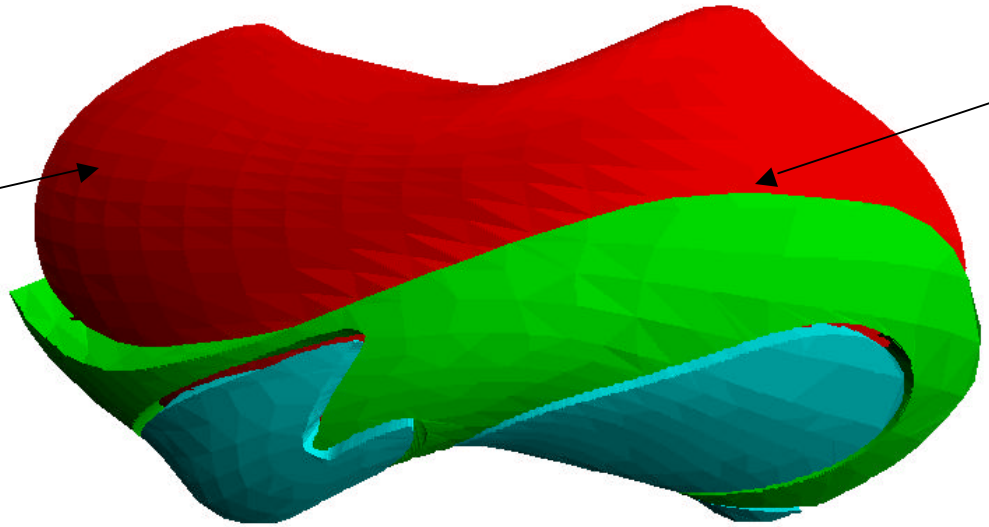
- Possible advantages are:
  1) pre-install coils on plasma-side of shell,
  2) assemble shell around a completed vessel

Options:

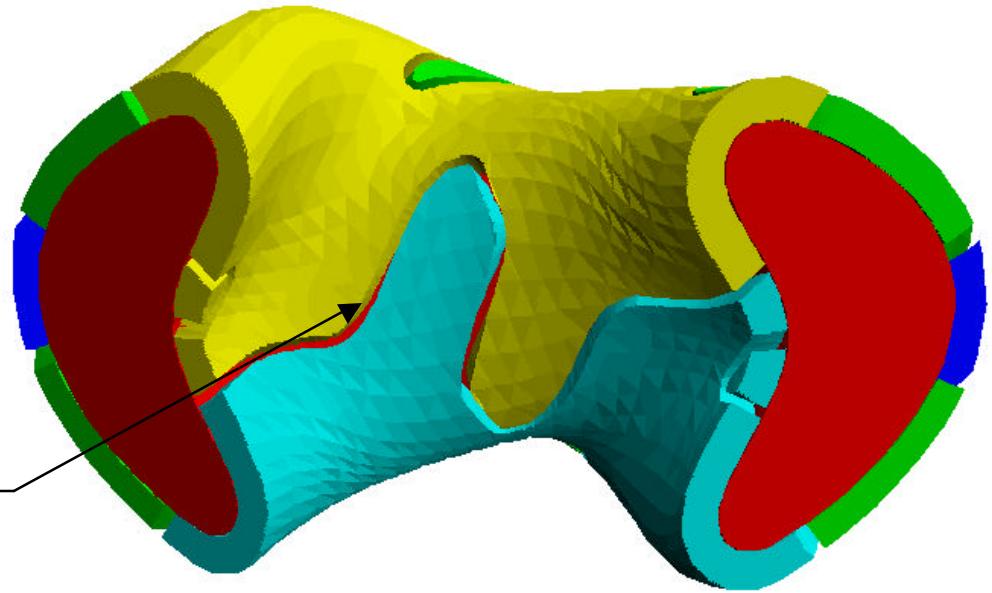
1) Upper/Lower Concept, 2 subassemblies (“The Bagel”)
2) Inner/Outer Concept, 4 subassemblies (“The Apple Core”)
3) Many Plates Concept, 9-15 subassemblies (“The Skull”)

Structural Shell Segmentation - Upper/Lower Concept, Outboard View

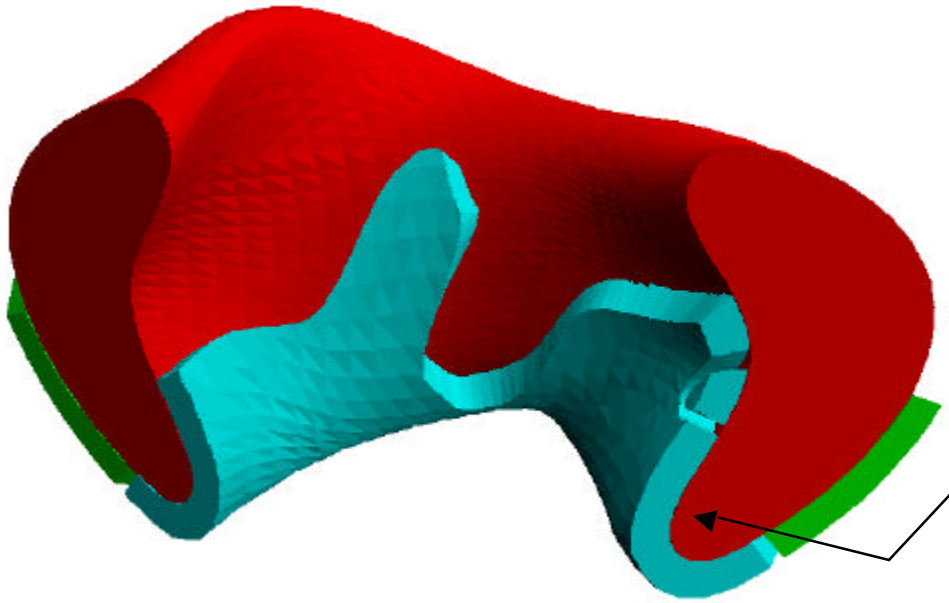




Structural Shell Segmentation - Upper/Lower Concept, Inboard View

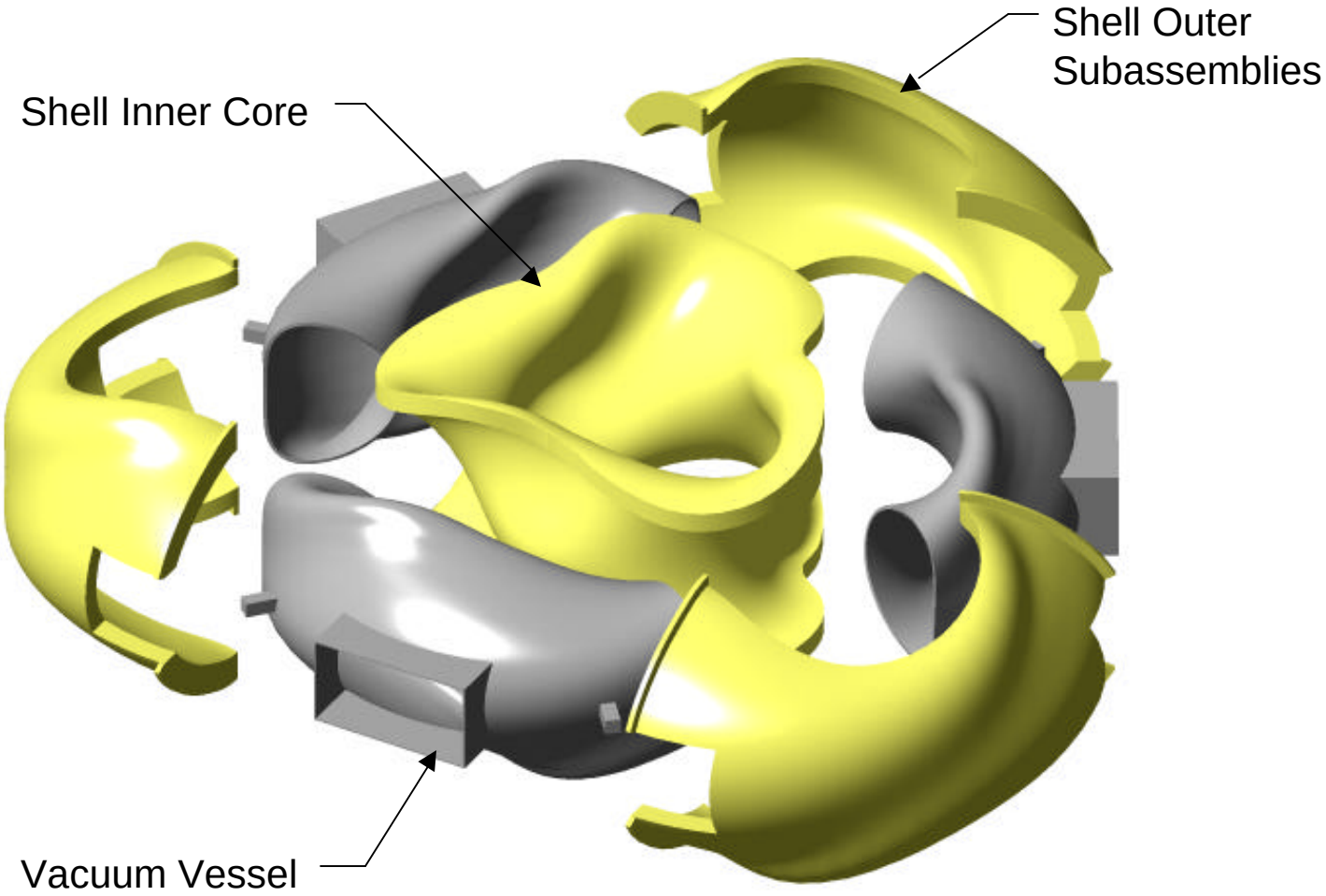


Inboard wavy PF does not present a good interface between upper and lower halves

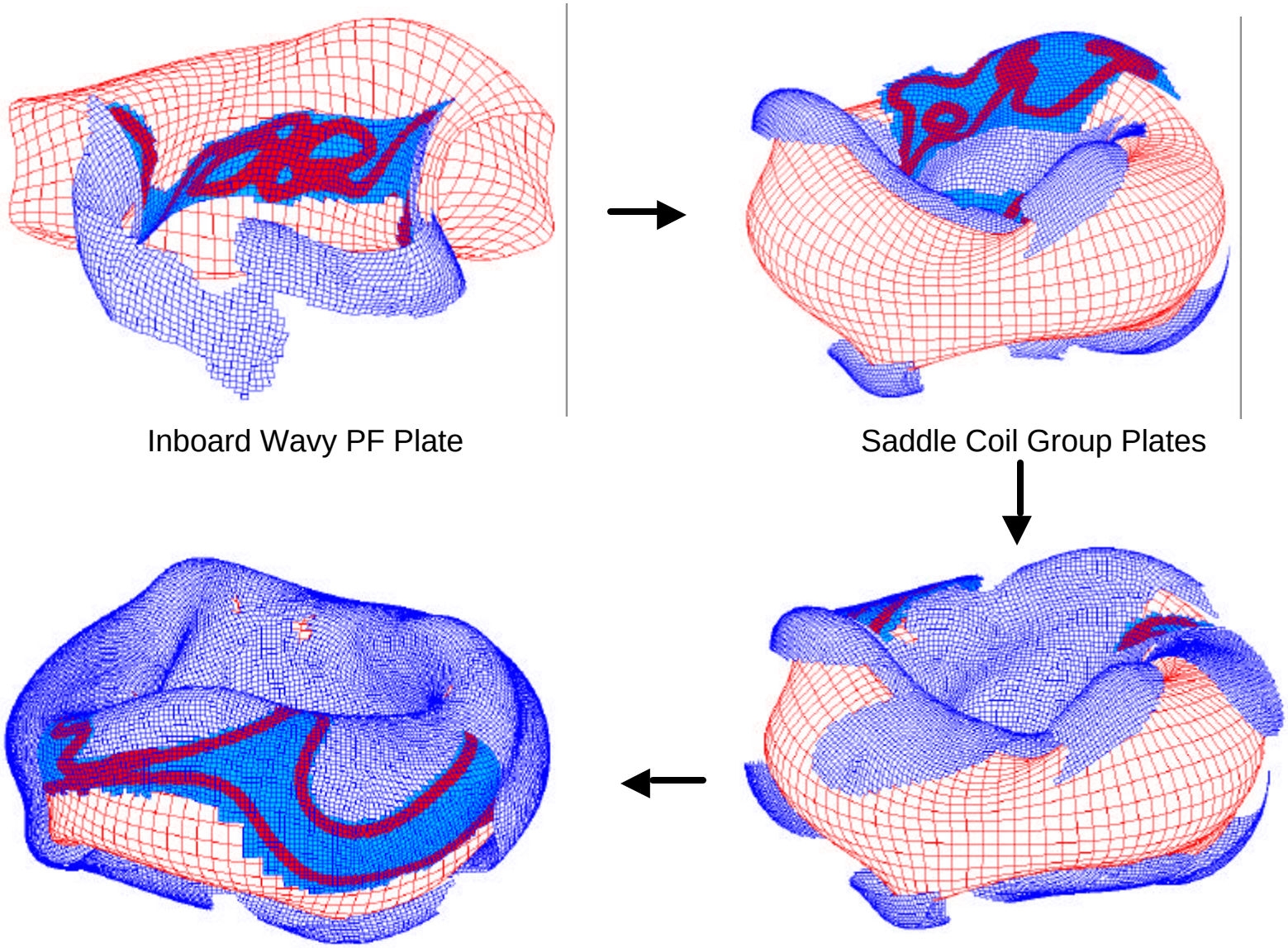


Vertical assembly around completed vessel is not feasible

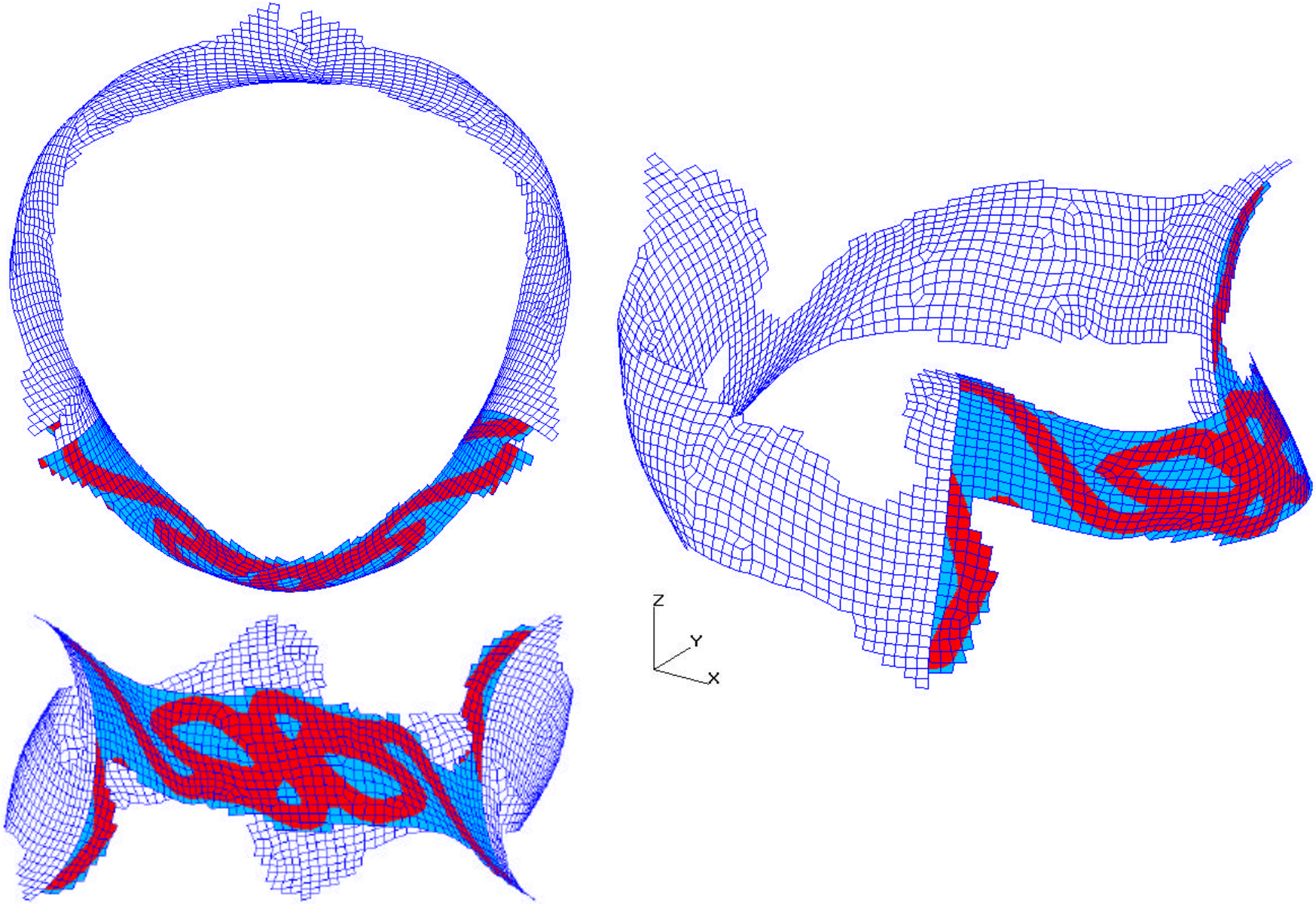
Structural Shell Segmentation - Inner/Outer Concept



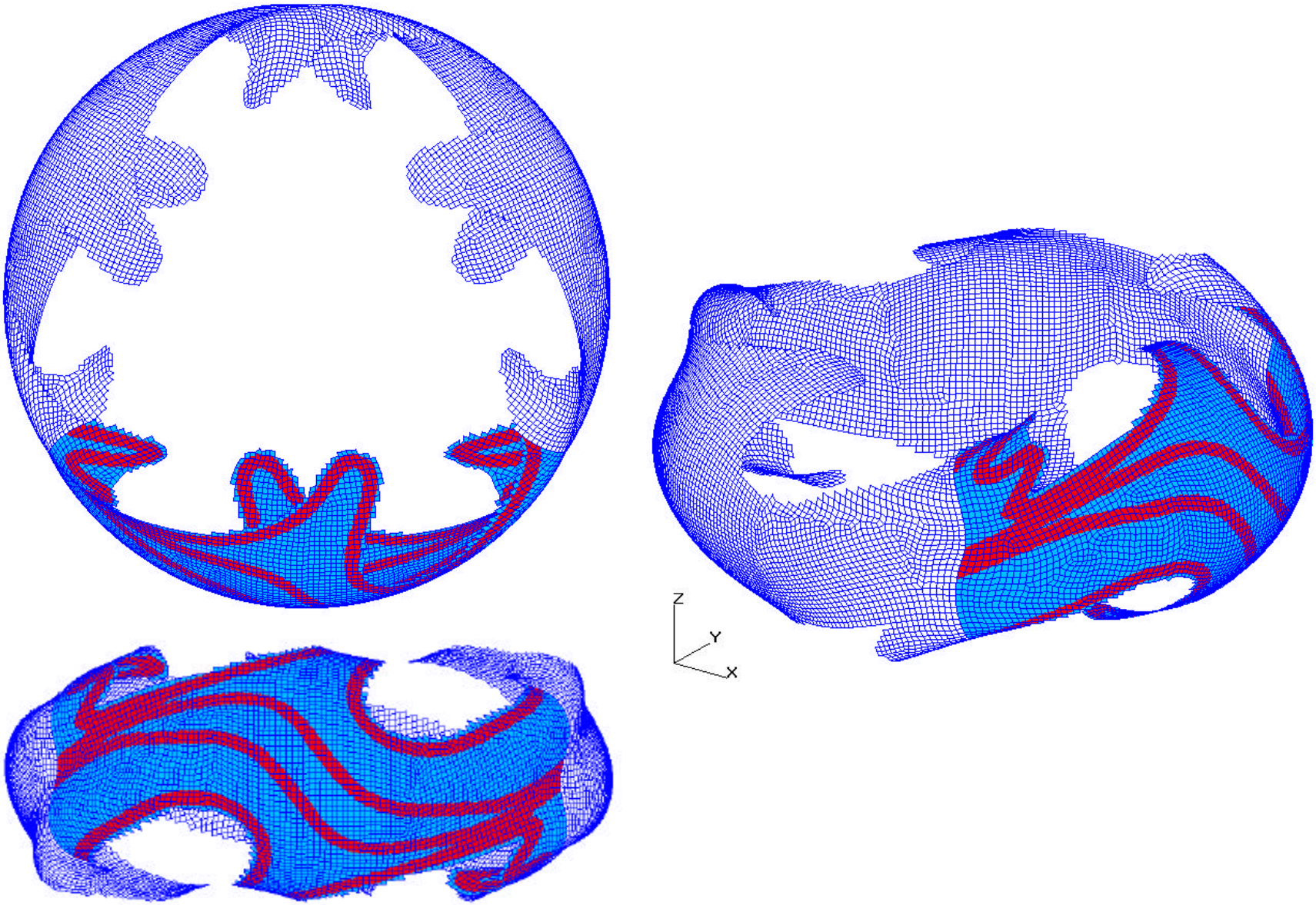
Structural Shell Segmentation - Many Plates Concept



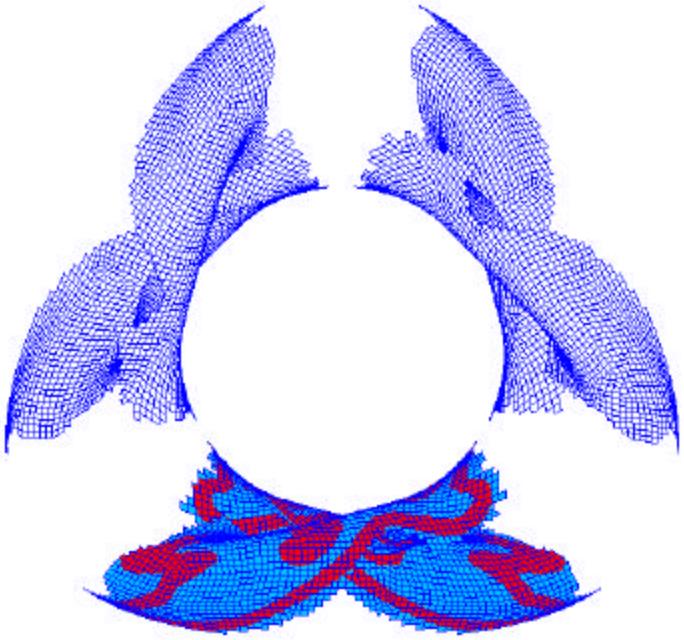
Structural Shell Segmentation - Many Plates Concept, Inboard Wavy PF



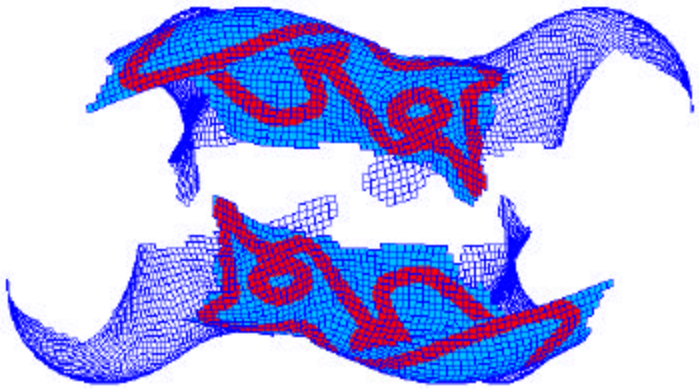
Structural Shell Segmentation - Many Plates Concept, Outboard Wavy PF



Structural Shell Segmentation - Many Plates Concept, Saddle Coil Group #1



PLAN



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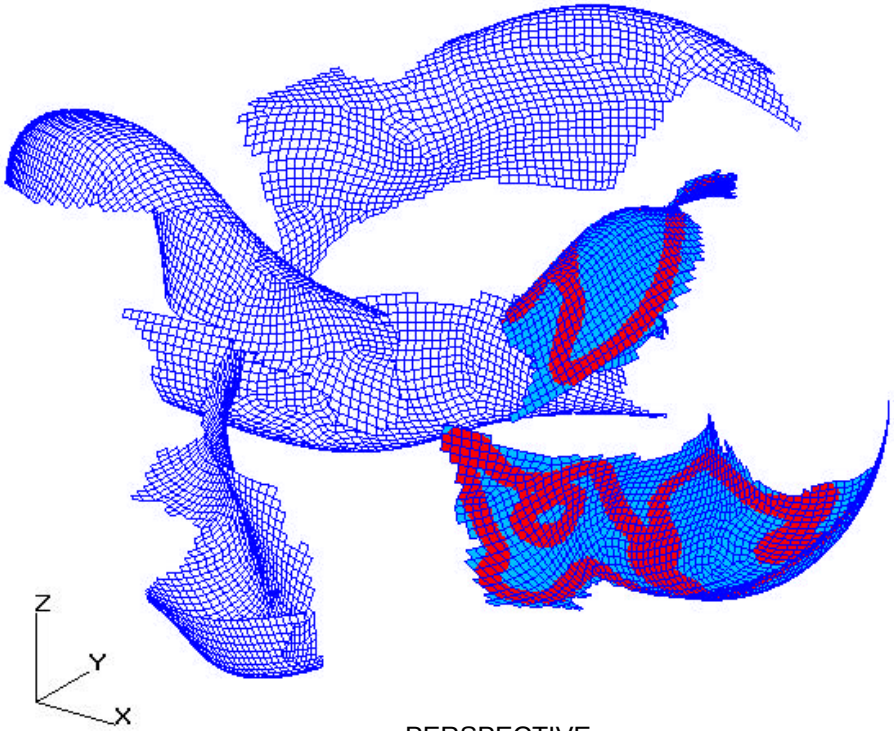
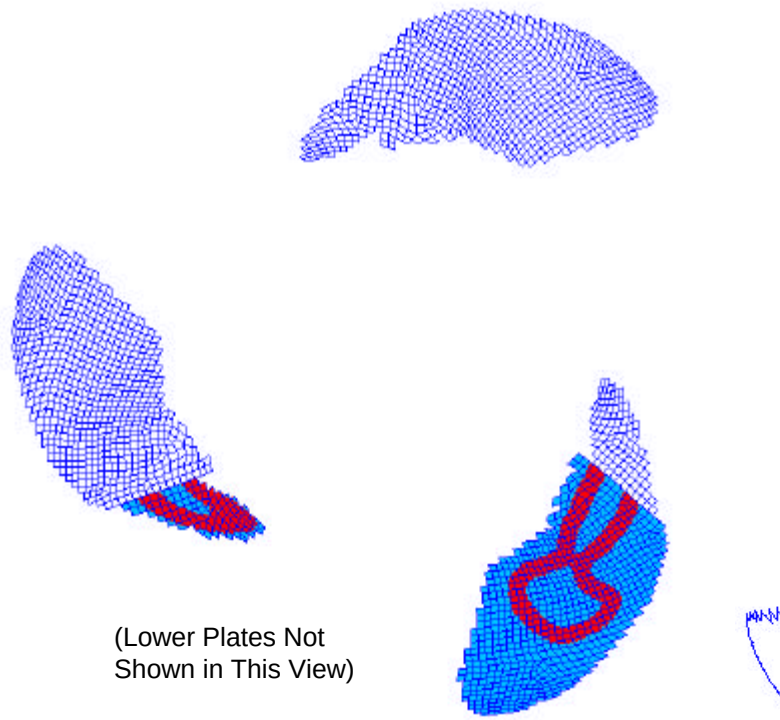


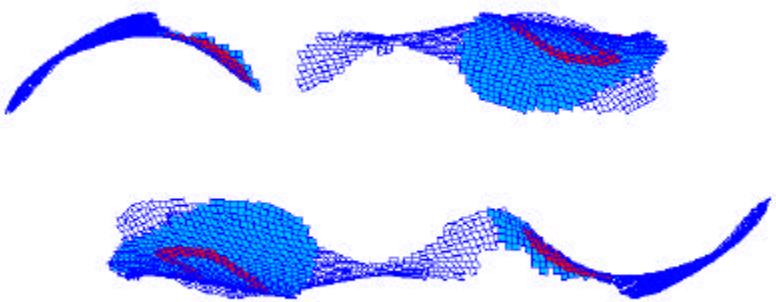
PERSPECTIVE

Structural Shell Segmentation - Many Plates Concept, Saddle Coil Group #2



(Lower Plates Not
Shown in This View)

PLAN



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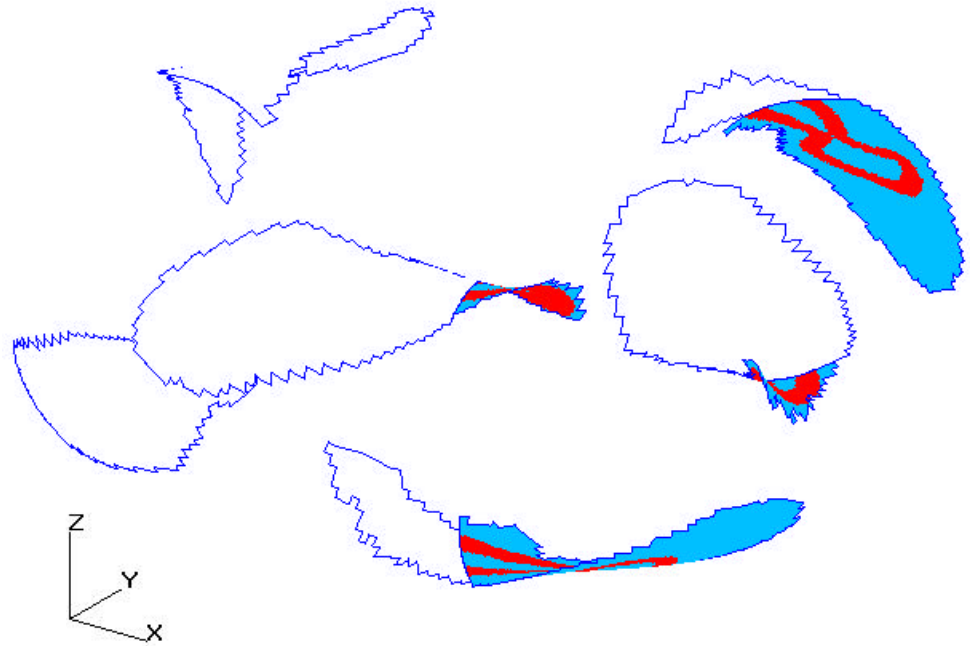


PERSPECTIVE

Structural Shell Segmentation - Summary

Upper / Lower Concept:

- Fabricated as two large, identical subassemblies
- Coils may be wound on plasma-side of shell
- Assemble around completed vacuum vessel?
- Requires change in inboard wavy PF configuration

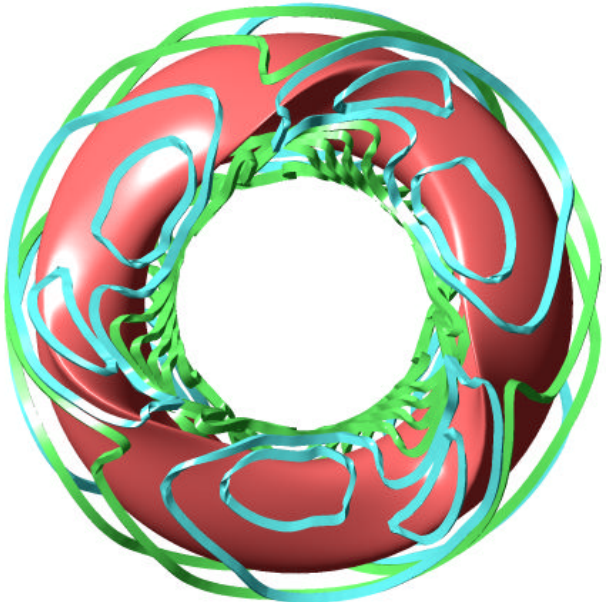
Inner / Outer Concept:

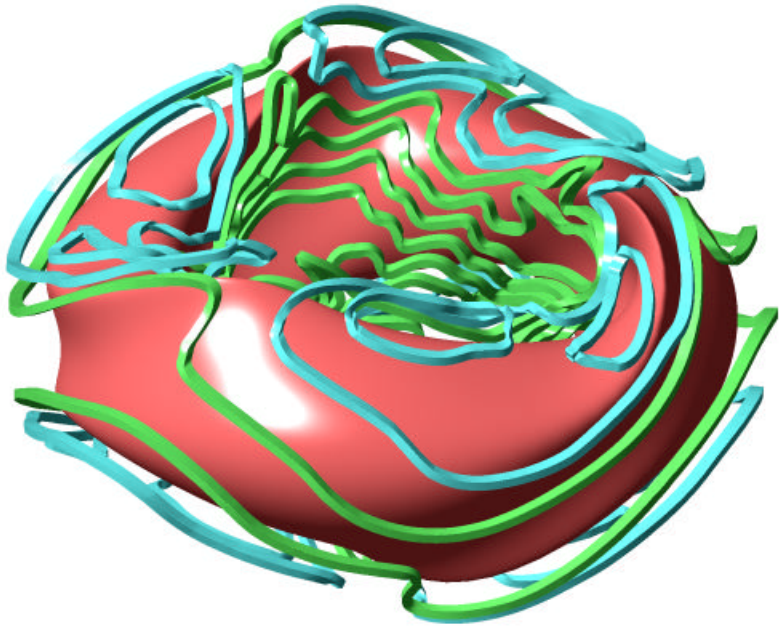
- One inner subassembly, three outer subassemblies
- Coils wound on outside of shell
- Vessel assembly sequence is integral with shell asm
- Works for any coil set

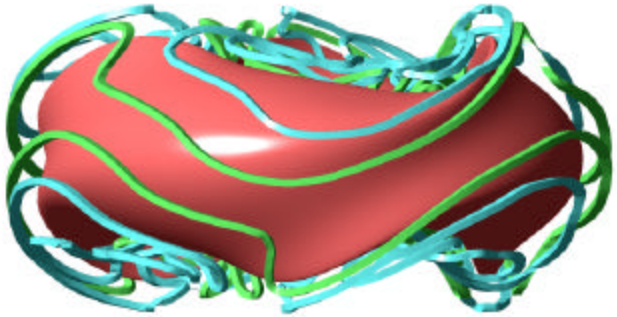
Many Plates Concept:

- Inner and outer rings, plus plates for saddle coils
- Coils wound on plasma-side of shell
- Assemble around completed vacuum vessel?
- More plates = more $$$, alignment problems

L=3 Option, Case 619 Conformal Coil Arrangement

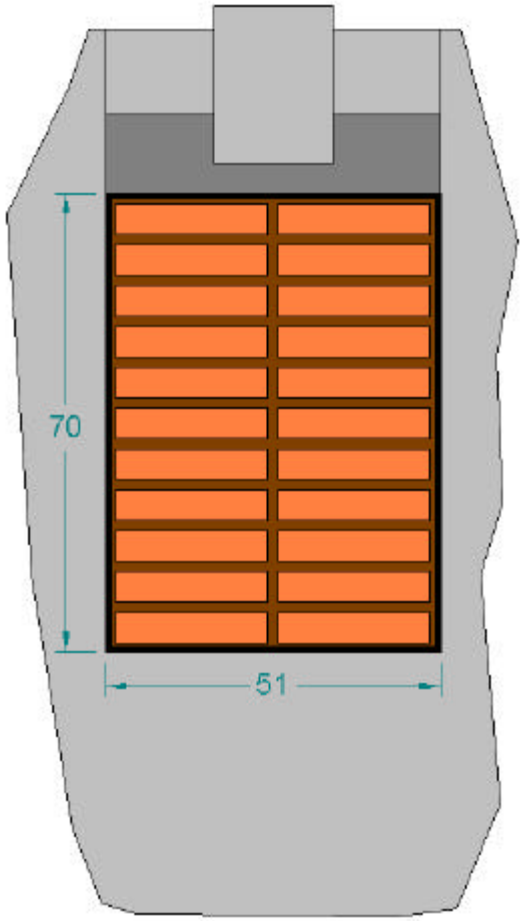




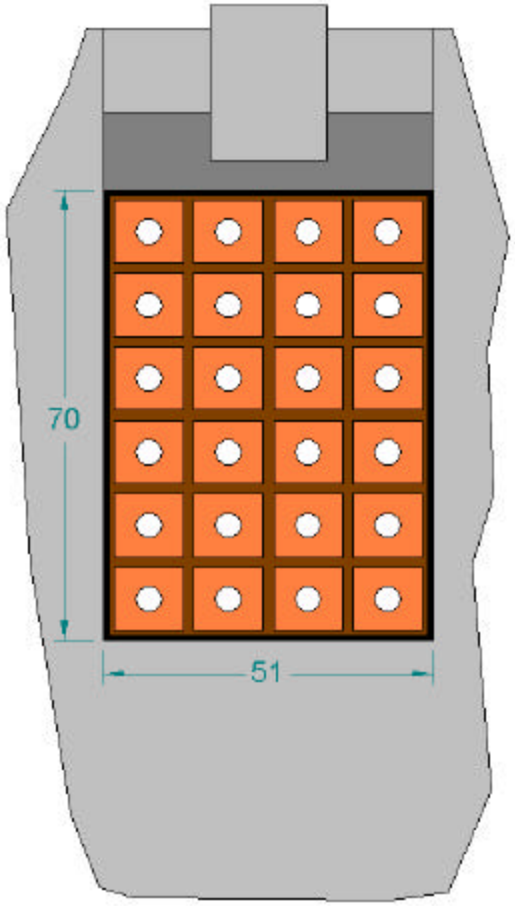


- 10 Unique Coils, 44 Total
- 215-kA per Coil at 2-T
- 5.1x7-cm Nominal Dims

L=3 Option, Case 619 Conformal Coil Winding Configurations



Cabled conductor, 23.1 x 4.6-mm
Packing factor = 0.75
No. Turns / coil = 22
Current / turn = 9.8-kA
Current density = 12.1-kA/cm2



Cabled conductor, 10.8 x 9.8-mm
Packing factor = 0.75
No. Turns / coil = 24
Current / turn = 9.0-kA
Current density = 13.0-kA/cm2

Conformal Coil Conductor Issues

Two room-temp winding configurations have been considered:

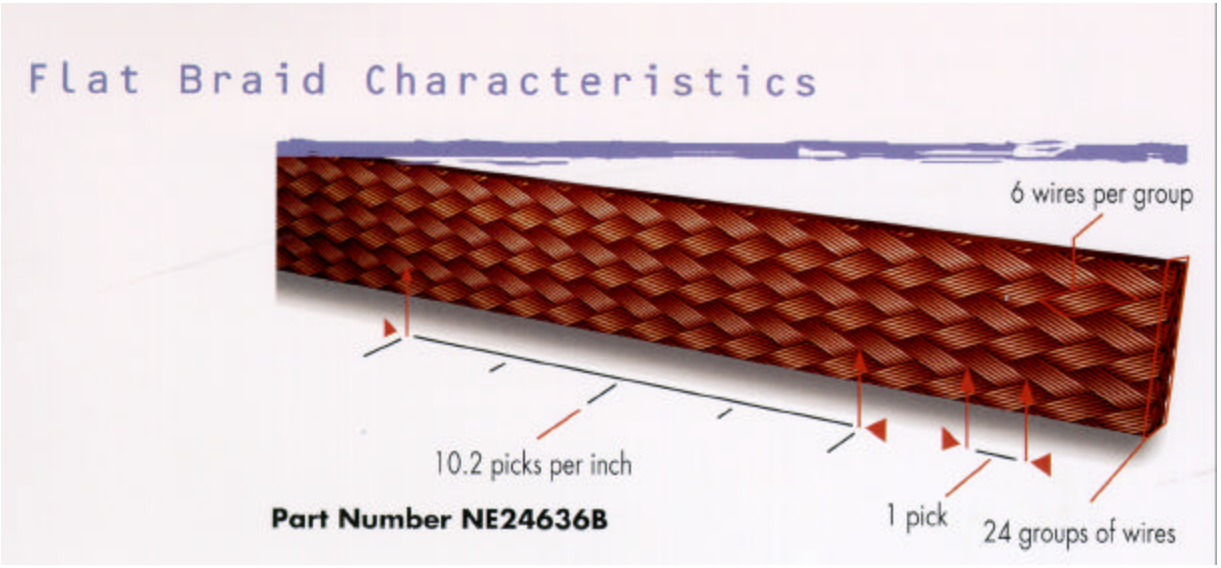
- Two-layer pancake winding, cooled by conduction to shell
- Four-layer winding with internal cooling

Issues with conduction-cooled option are:

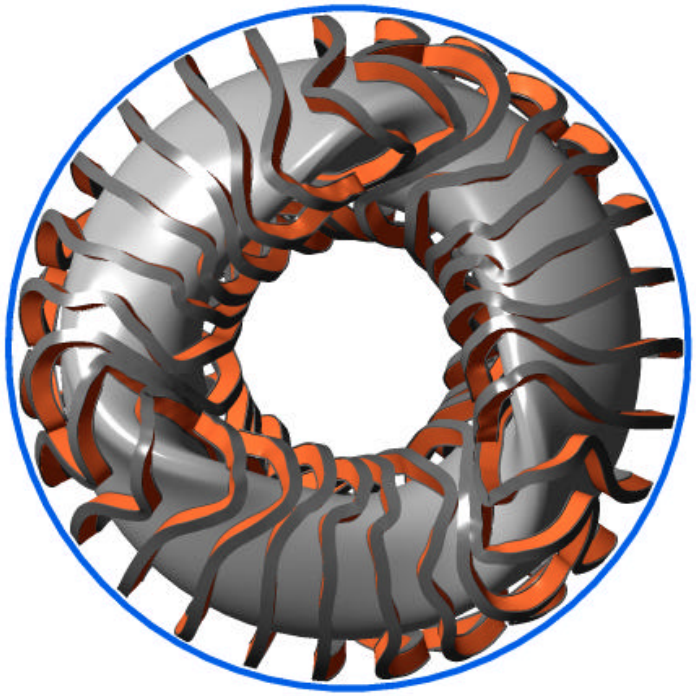
- How does aspect ratio of conductor affect manufacture and installation?
- Does concept really meet cool-down requirements? (subject of R&D)

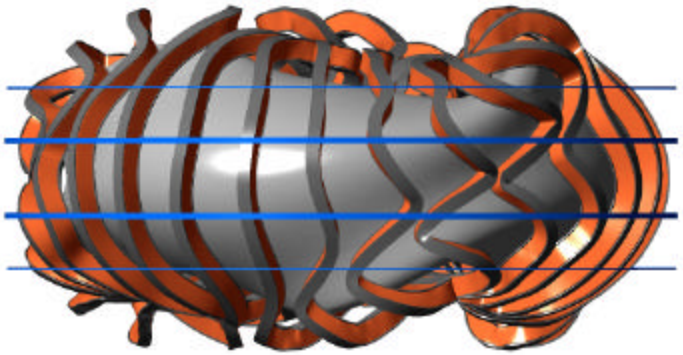
Issues with internal-cooled option are:

- How does flow passage affect conductor manufacture (packing factor)?

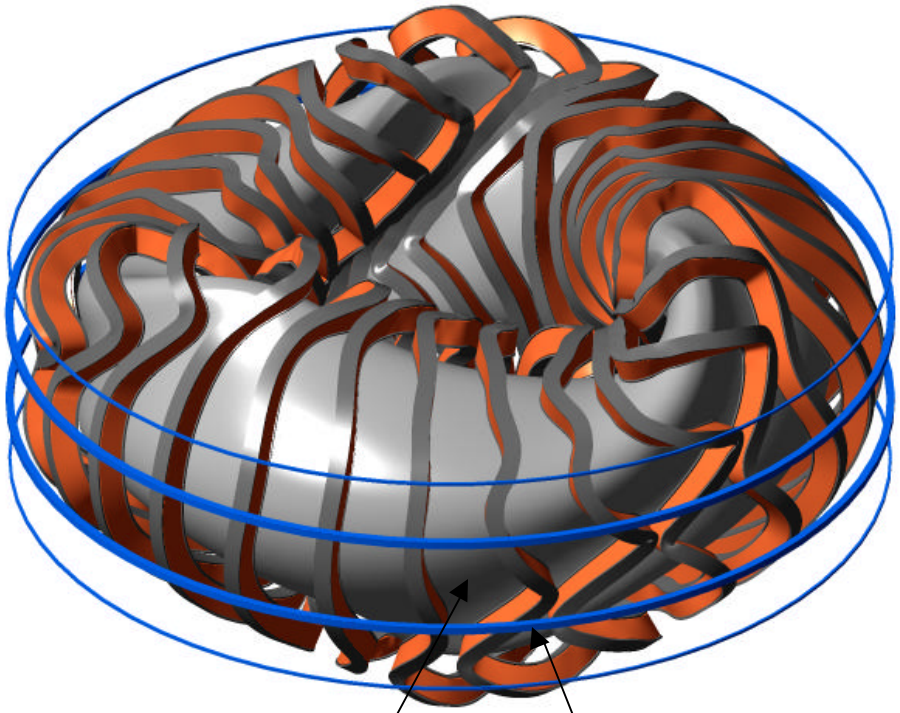


Modular Coils, Case 0424 General Arrangement



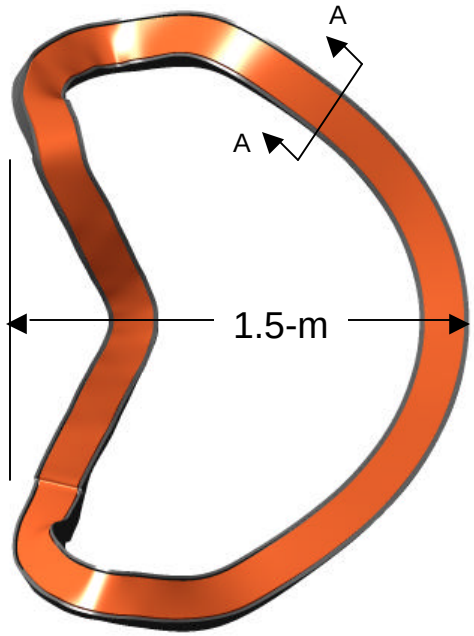


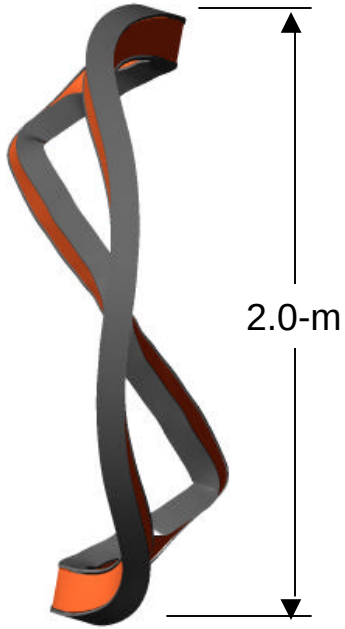
- Total Number of Coils = 27
- No. Unique Coils = 5
- Coil Current = 529-kA at 2-T
- Nominal Dims = 9 x 16-cm

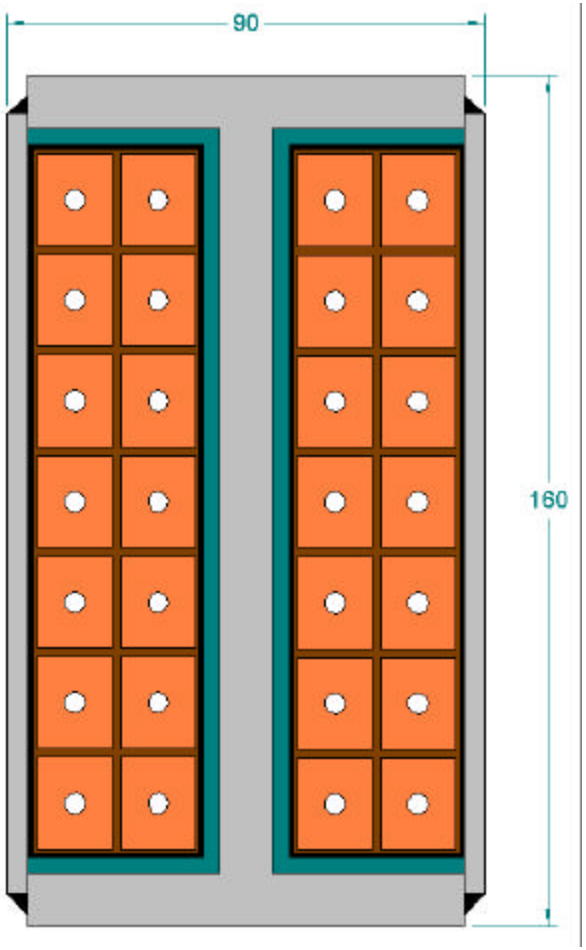


Modular Coils, Case 0424 Winding Configuration

- Cabled conductor, 14 x 17-mm, 4-mm dia hole
- Packing factor = 0.75
- No. Turns / coil = 28
- Current / turn = 18.9-kA
- Current density = 10.9-kA/cm2

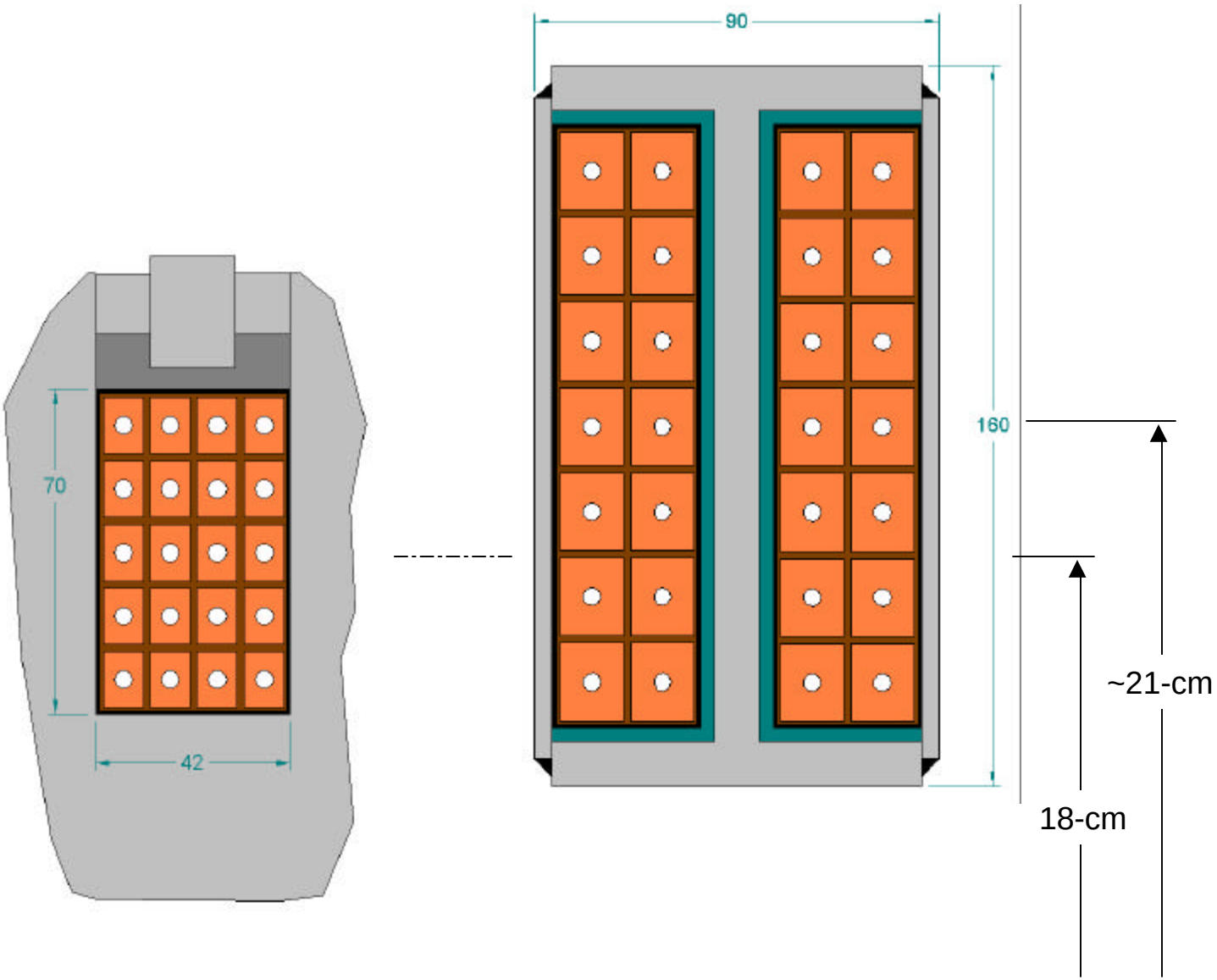




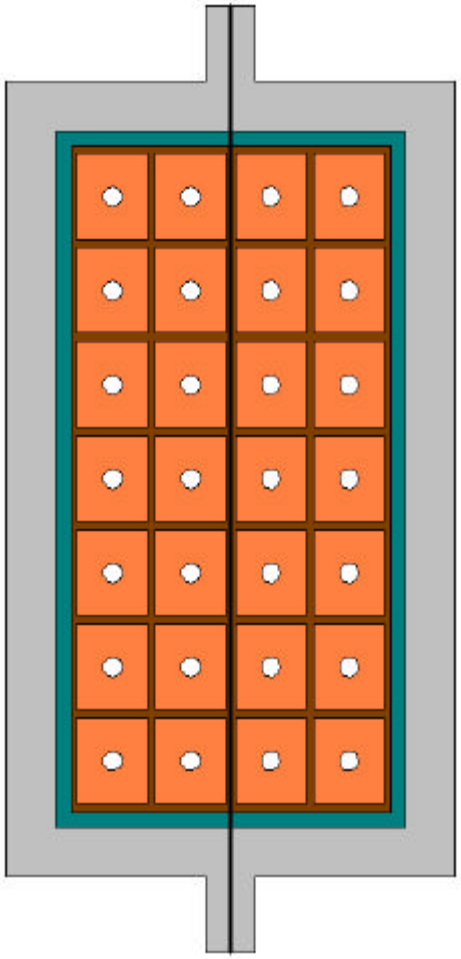


Section A-A
(Dimensions in mm)

Modular Coil Cross-Section Compared To Conformal Coils (Case 536)

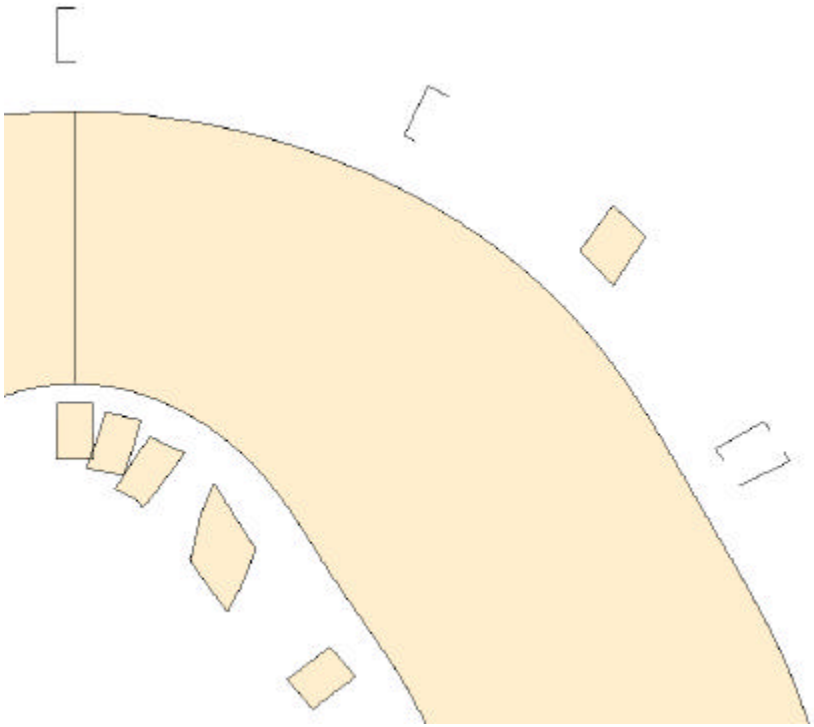


Modular Coils, Case 0424 Alternate Winding Configuration

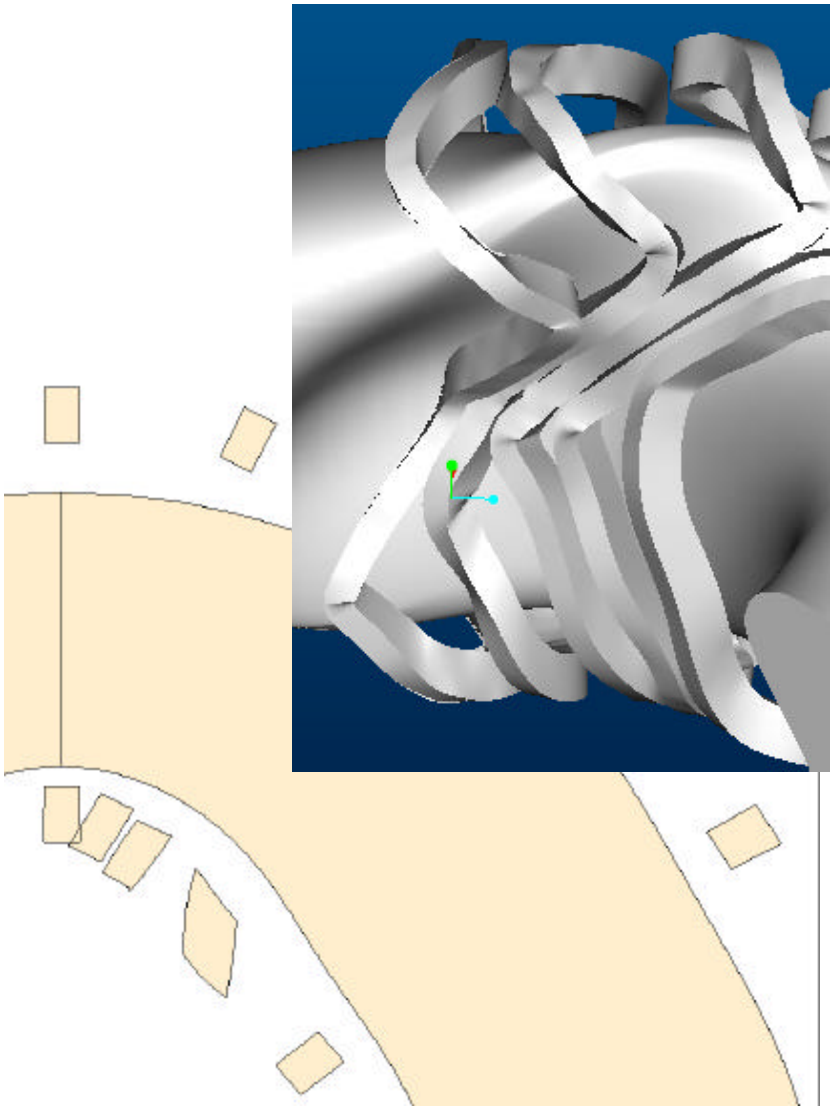


Modular Coils, Case 0424 Coil-to-Coil Interference

- Finite cross section has interference problems
- Local adjustment of coil twist is being explored
- Best method is to be determined



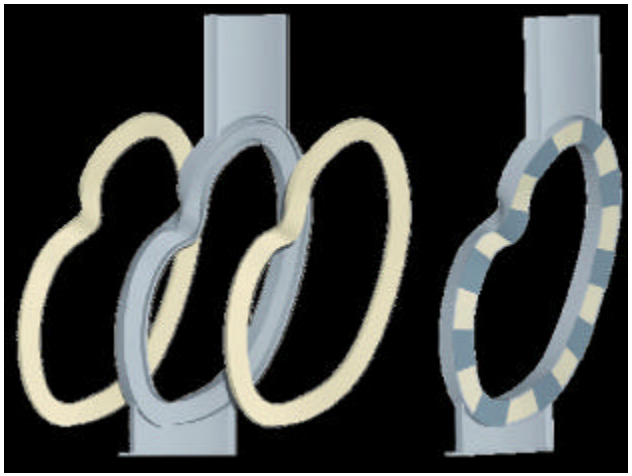
Plan Cross-Section Before Adjustment



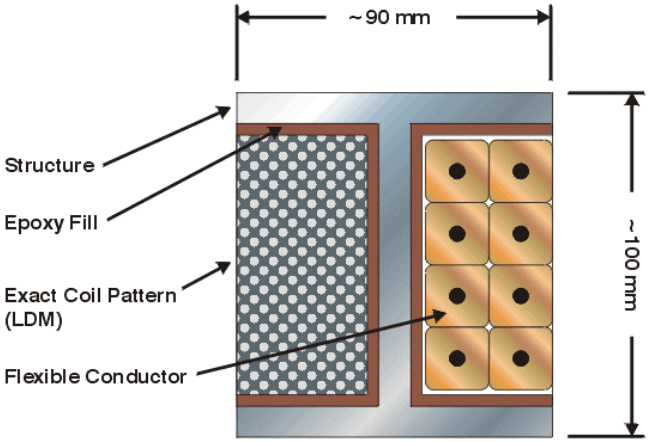
After Adjustment

Modular Coils, Case 0424 Fabrication and Assembly

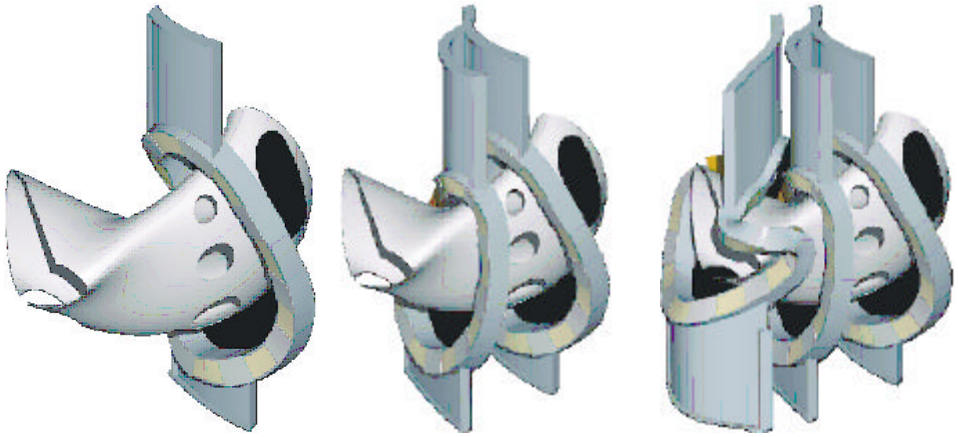
- Coil pattern is made by rapid prototype methods and potted into cast structure to form winding cavity
- Coils are assembled around half-period sectors of vacuum vessel, corner coils at machine asm



Coil Structure, Windings, and Side Plates



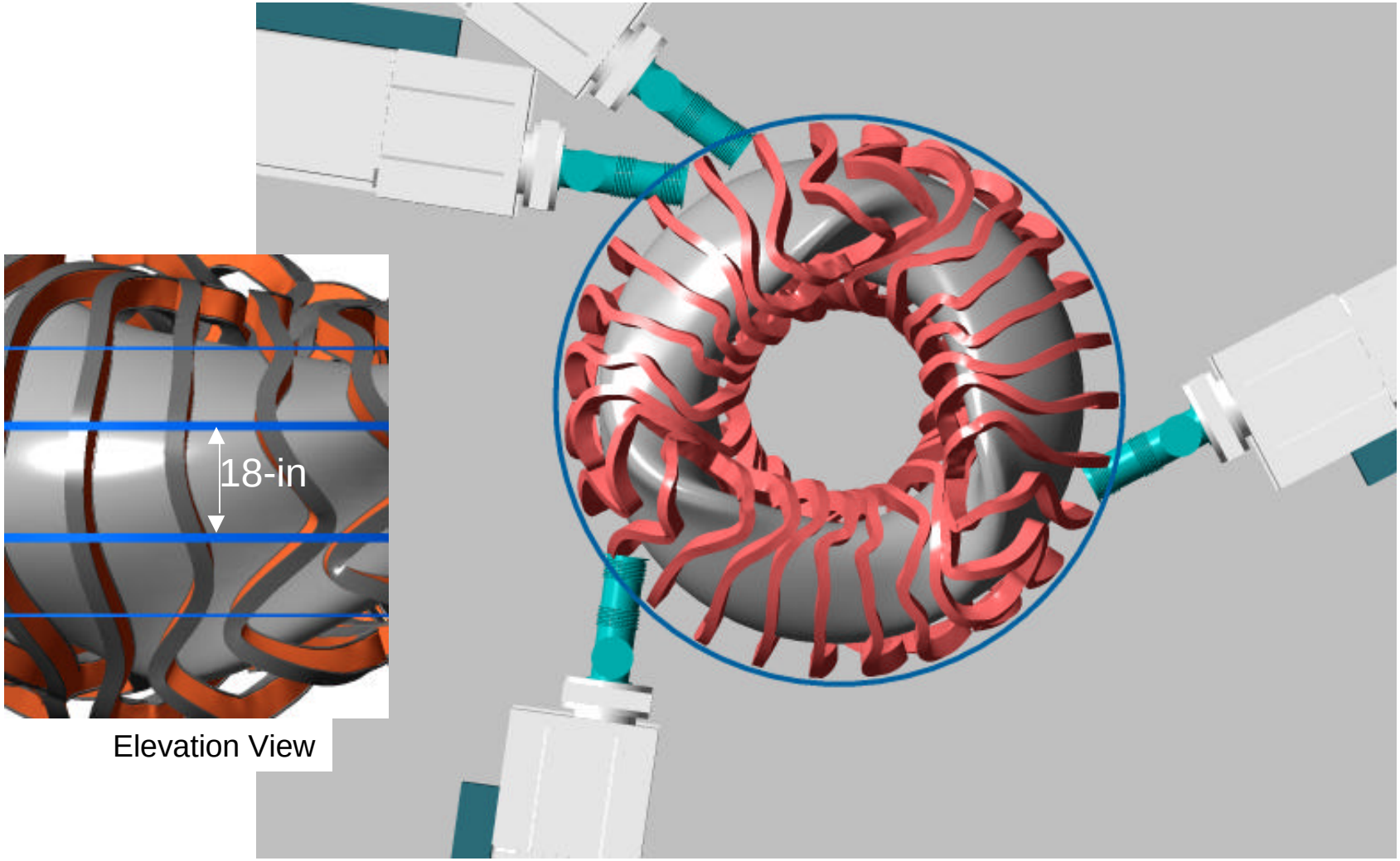
Coil Winding Section



Assembly Sequence based on QOS Study

Modular Coils, Case 0424 Access Issues

- Outboard midplane access is ~14 x 18-in



Elevation View

Design of Close-Fitting Coils, Conclusions

- Each of the C82 options has been developed to some level

- New configurations may have advantages, such as
  1) winding on plasma-side of shell
  2) bagel-type structural shell

Near-Term Action Items:

- EM loads and structural analysis (modular coils)
- Thermal/hydraulic analysis of conductor options
- Develop method of shape optimization (modular coils)
- Perform diagnostics access evaluation
- Develop conformal coil costs relative to In-PBX Option