Structural Analysis of Vacuum Vessel for Proposed Compact High Field Tokamak (ADX)

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Introduction: A tokamak is a device that uses magnetic confinement to study plasma. The goal of a tokamak is to use high magnetic fields to contain the plasma and produce nuclear fusion that can be used for power generation. Fusion power is a function of the magnetic field strength and the plasma performance. Recent advances in high temperature superconductors could allow tokamaks to run at higher fields, increasing the performance of the plasma to reactor levels. Research would then need to focus on improving the support systems of the tokamak. MIT's Plasma Science Fusion Center (PSFC) and collaborators are proposing a machine, the Advanced Divertor eXperiment (ADX) that would be designed to test new technology for these systems at reactor level heat fluxes and magnetic fields. [1] COMSOL has been used to analyze the proposed ADX vacuum vessel to determine loads and stresses induced during a plasma disruption.

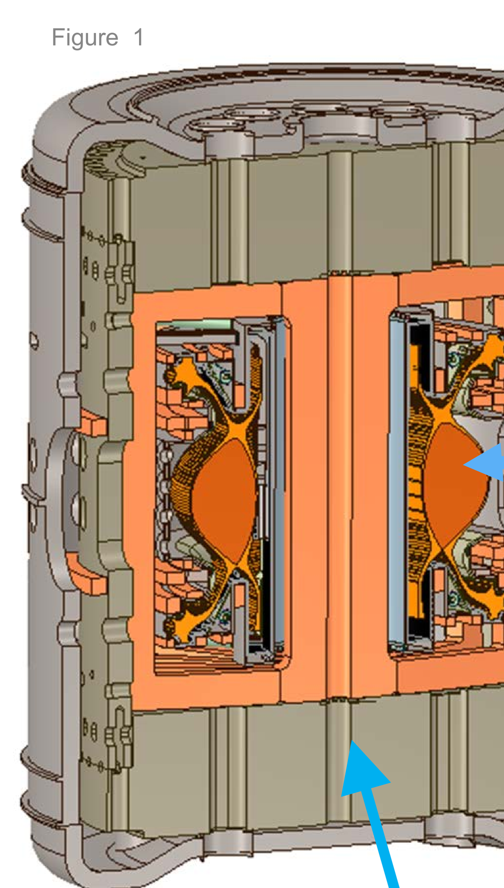

Figure 1

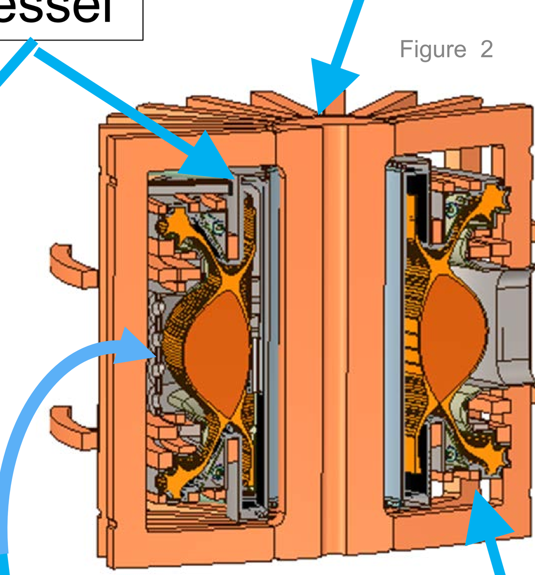

Figure 2

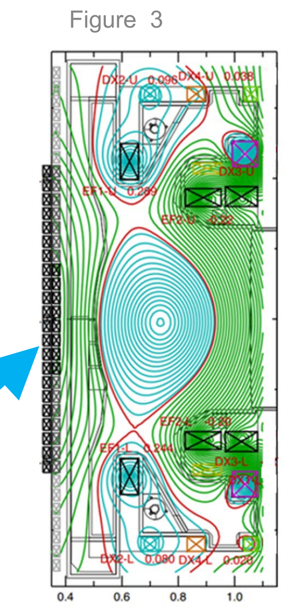
Figure 3

Poloidal Field Coils are used to create magnetic fields that contain the intense plasma.

One challenge for tokamaks is to develop an advanced divertor that can accept the heat and particle fluxes that escape the core plasma. ADX will be capable of testing a variety of different divertor configurations.

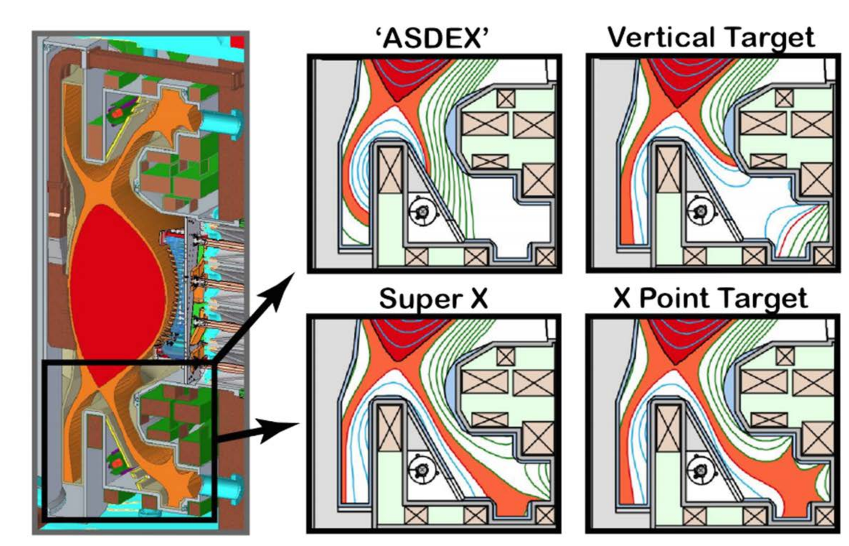

Figure 4

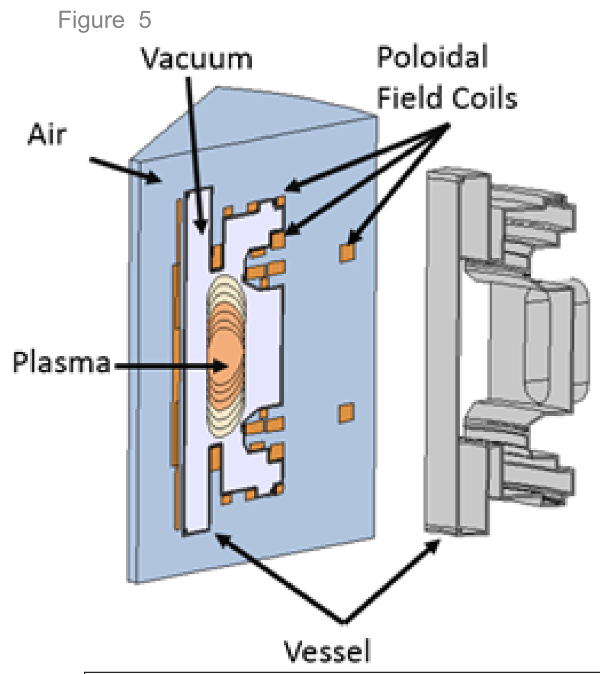

Figure 5

Cyclic Symmetry model used in Comsol. Using 'mf' physics, External Current Density is input to the poloidal field coils and plasma and the resultant B fields are calculated.

A disruption where the plasma moves up in the vessel (VDE) before losing its current is simulated by changing which volumes carry current. Times 0-0.01s show the plasma rising in the vessel with full current (1.5MA) and times 0.01s-0.011s show the current quench when the plasma current drops to 0

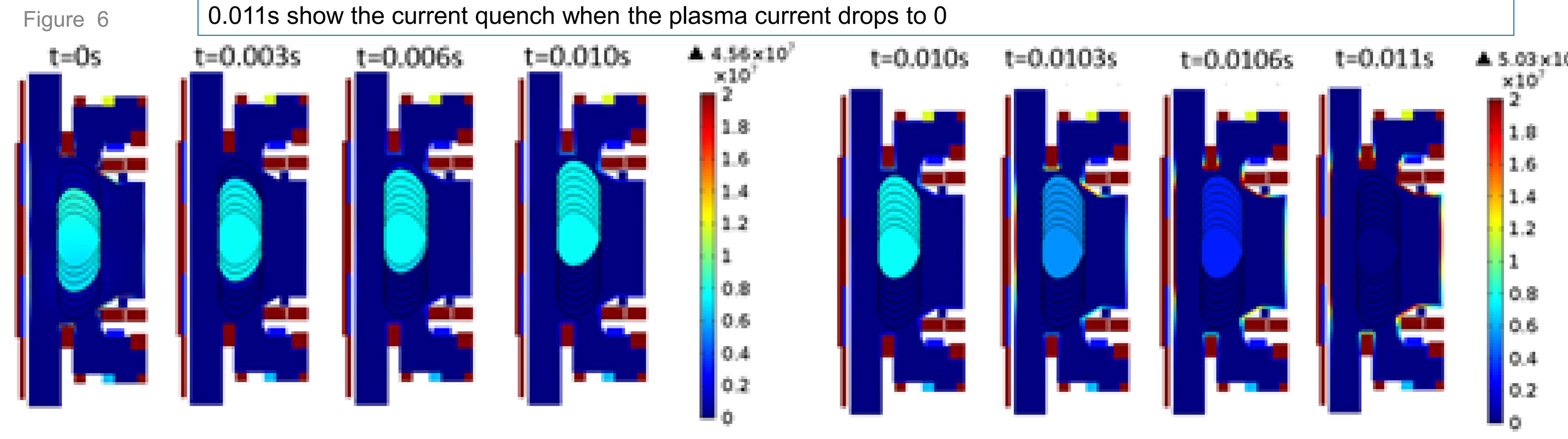

Figure 6

The changing plasma current results magnetic fields in the vacuum vessel, and these rapidly changing fields generate voltages which cause eddy currents in the conductive vessel. Fields rise slowly as the plasma moves closer to the top of the vessel and then fall rapidly during the current quench.

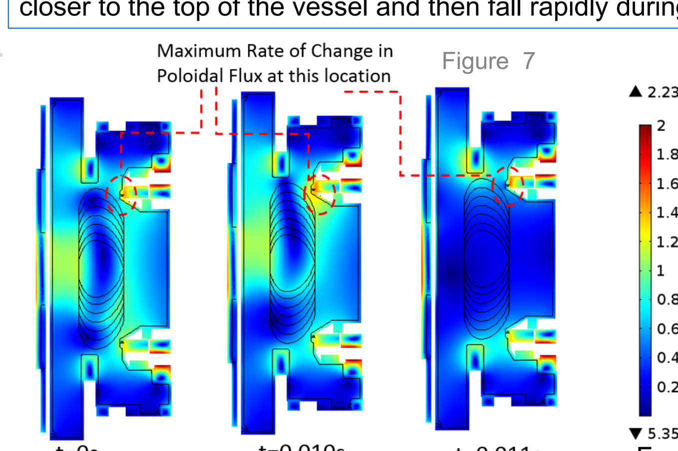

Figure 7

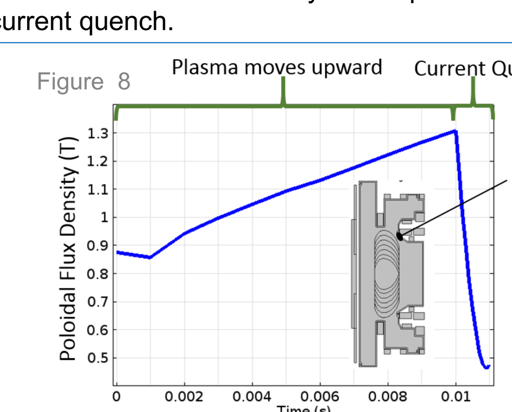

Figure 8

In addition to the poloidal fields due to the PF coils and plasma, there is a toroidal field

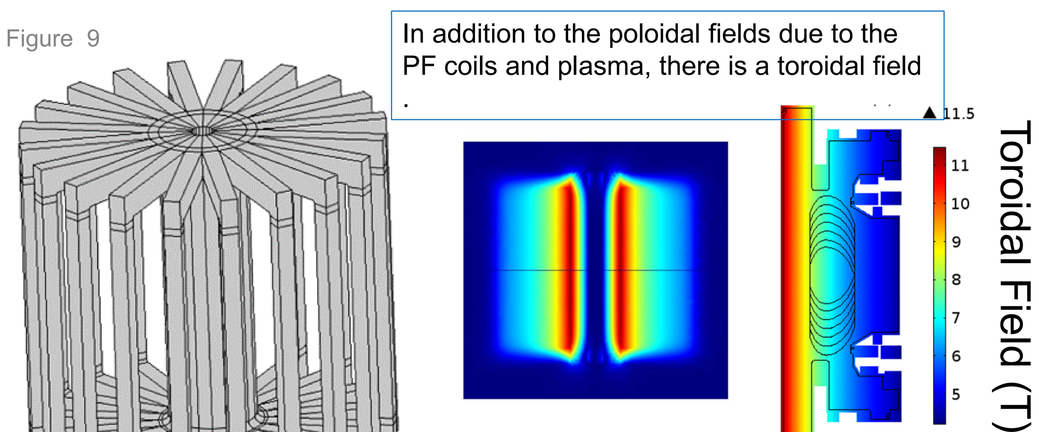

Figure 9

Eddy Currents (A/m2) generated in vessel during Current Quench. Currents travel in toroidal direction (except around cutouts like the port). This is advantageous because it keeps them from crossing the large toroidal field.

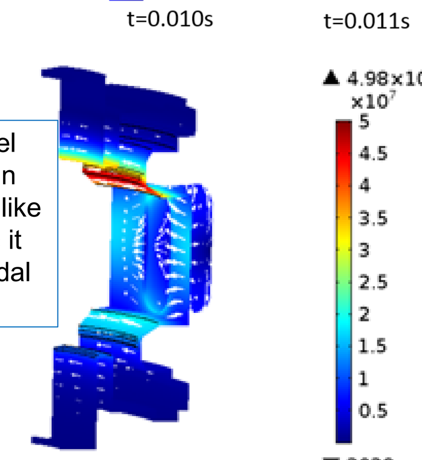
Figure 10

Forces due to Eddy Currents (JxB) are highest at the upper EF pocket nearest where the plasma collapses.

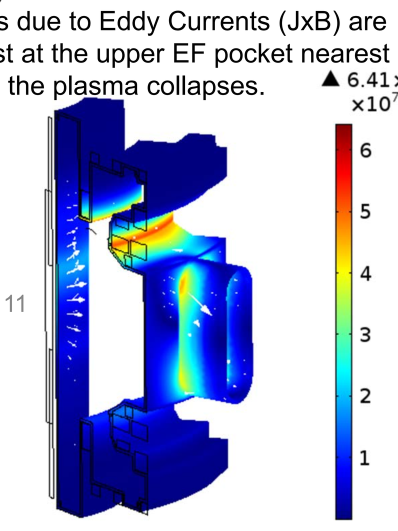
Figure 11

Loads from mf model are mapped to structural model with following BC's:

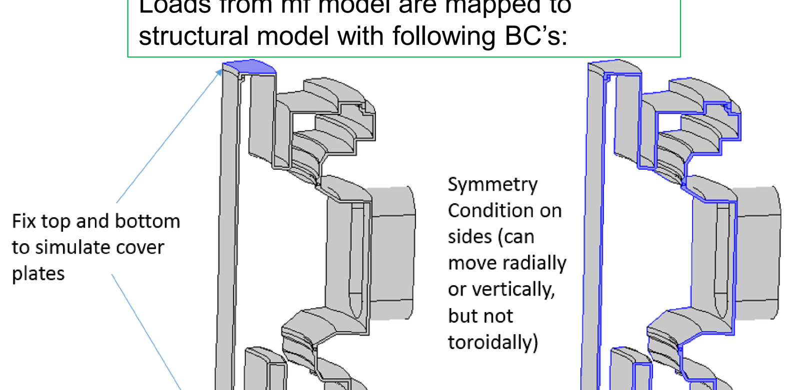

Figure 12

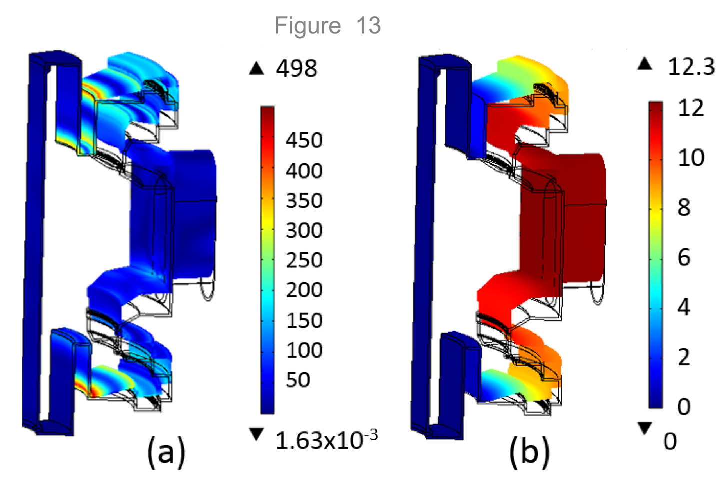

Figure 13

(a) Stress (MPa) and (b) Displacement (mm) are too large for ADX as designed. Stress exceeds 2/3 yield criteria. Need to add more supports.

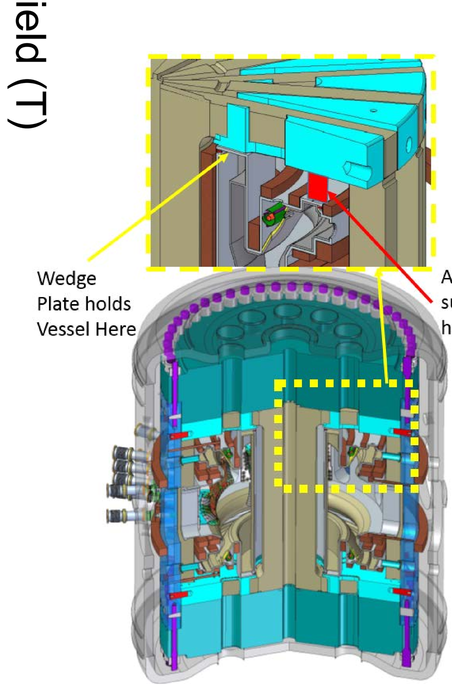

Figure 14

Add support here to connect back of vessel to wedge plate. This reduces stresses (a) and deflections (b) to allowable limits

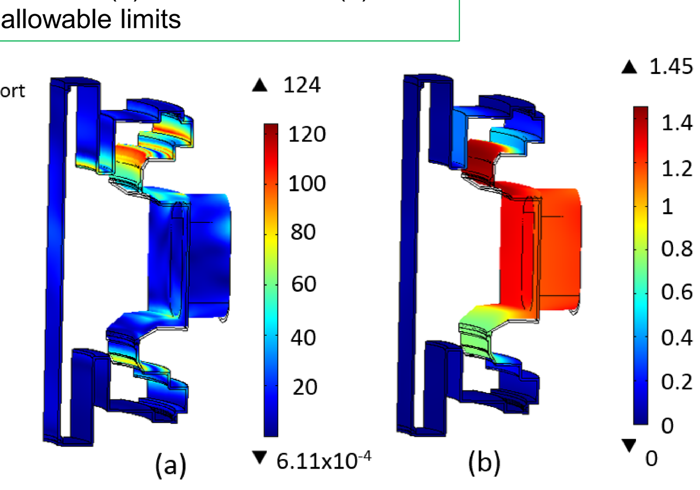

Figure 15

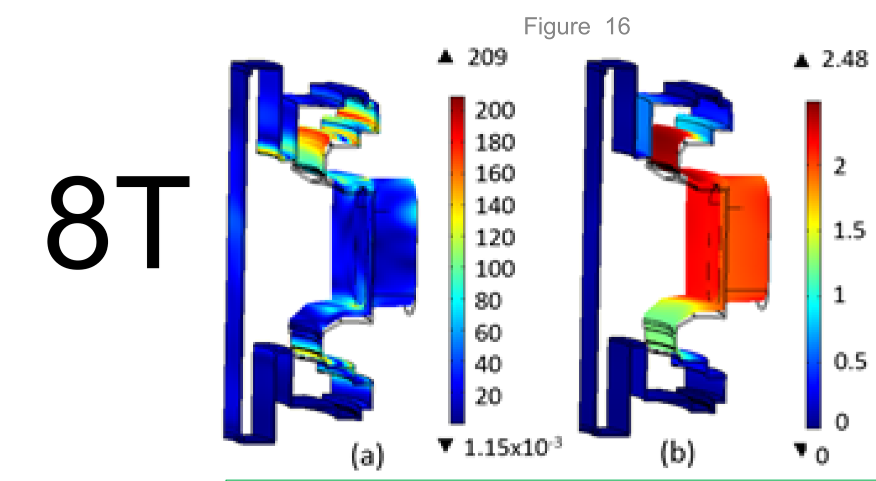

Figure 16

With a power system upgrade, we would like the ability to run at 2MA/8T. With the added supports, the ADX vessel will be able to withstand a disruption at this performance level.

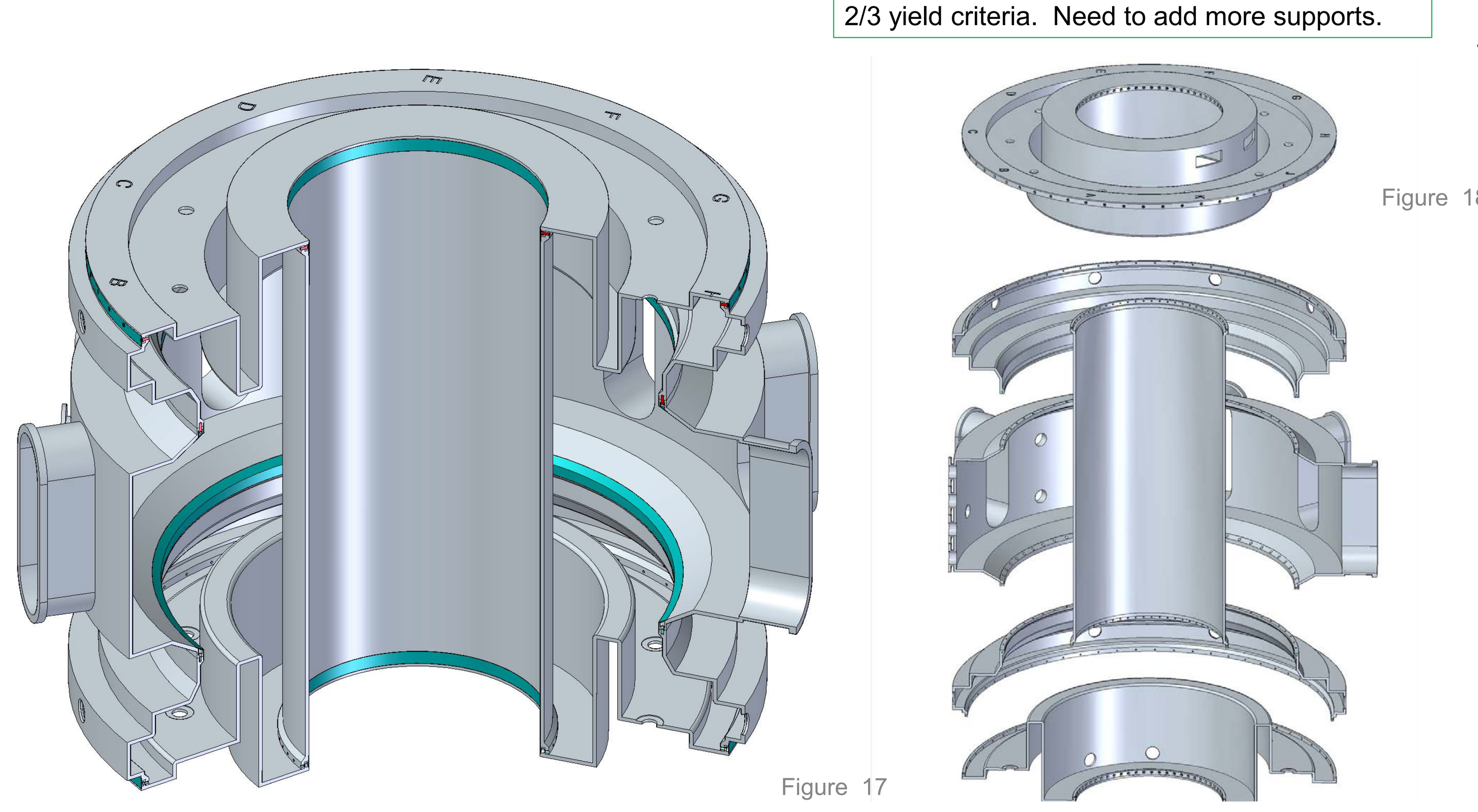
Figure 17

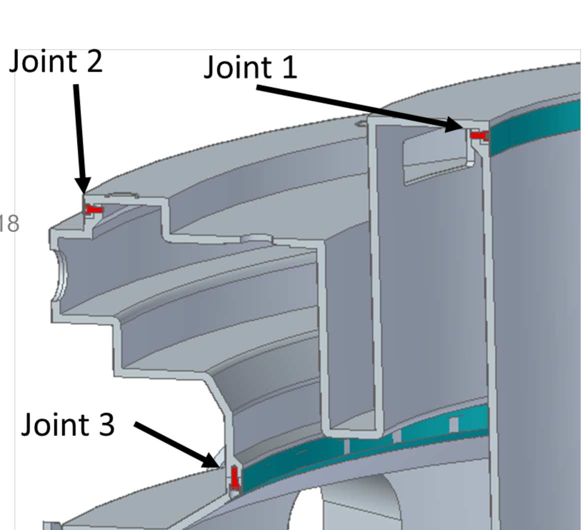

Figure 18

Joint	Number of Bolts Required to Carry max Load During VDE
Joint 1	3
Joint 2	32
Joint 3	18

By integrating the stress at the joints in the COMSOL model, we find the load that the bolts will need to carry. The Grade 8 bolts will be preloaded to 90% yield. 32 bolts will be able to carry the max load predicted by COMSOL without exceeding the preload and ADX is designed to have 60 bolts.

Conclusions:

COMSOL Multiphysics has been used to predict the loads, stresses and displacements on the current design for the vacuum vessel for the proposed Advanced Divertor eXperiment (ADX) tokamak.

- 'mf' physics interface was used to build a cyclic symmetry model of the tokamak, including magnetic field coils and the plasma, and simulate a VDE disruption including plasma movement and current quench. This model predicts the fields, eddy currents and Lorenz forces resulting in the vessel due to a disruption.
- Forces mapped to 'solid' physics interfaces where stresses and displacements predicted
- Stresses and Displacements above allowable for original design, but can be brought down to allowable limits with additional restraints.
- Loads carried by bolts holding shells together do not exceed preload

References:

1. B. LaBombard, et.al, "ADX: a high field, high power density, advanced divertor and RF tokamak," Nuclear Fusion, vol. 55, pp 1-25, May 2015.