Prediction of Magnetic Fields, Eddy Currents, and Loads in a Tokamak for a Disruption Alcator for C-Mod's Advanced Outer Divertor

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Introduction

A tokamak is a device that uses high magnetic fields to confine a superheated plasma that is used to study nuclear fusion.

Alcator C-Mod

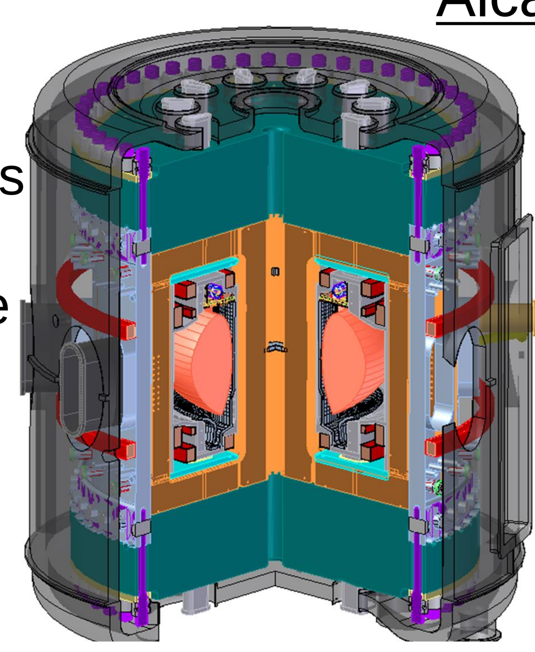


Fig. 1

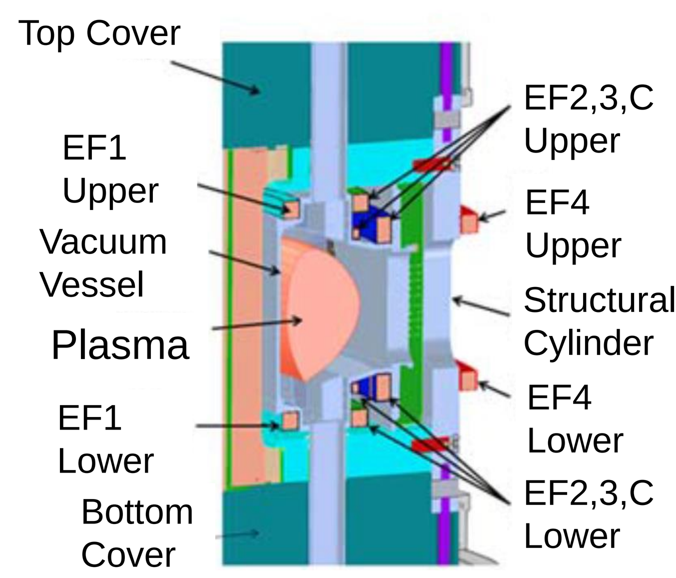


Fig. 2, C-Mod Geometry

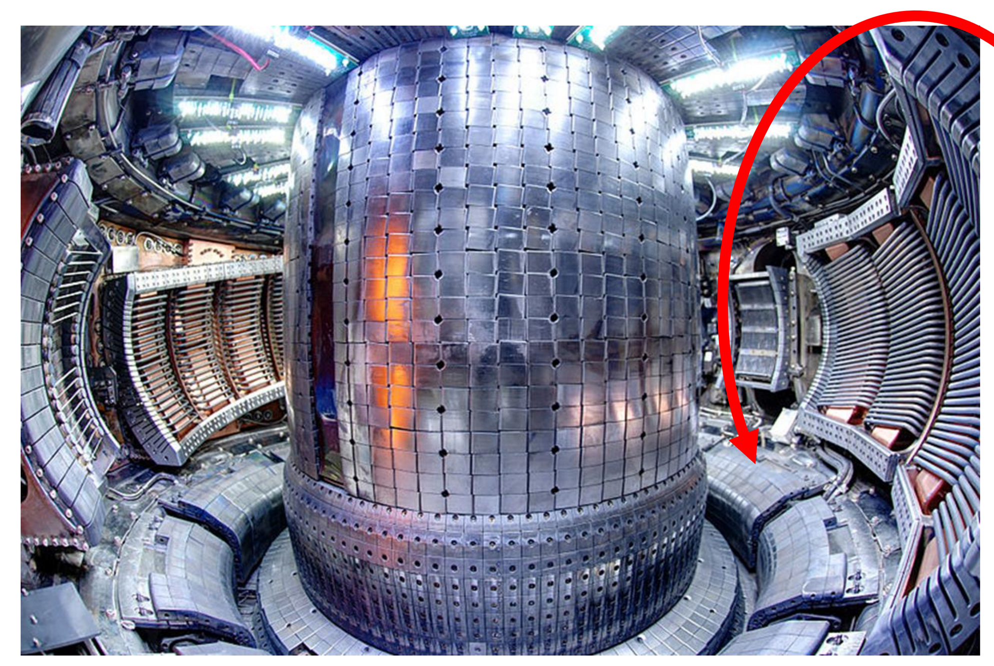


Fig. 3: Photo of Interior of C-Mod

One important component of a tokamak is the divertor. Alcator C-Mod has a unique divertor system that uses specially shaped magnetic fields to "scrape" away the cooler, outer edge of the plasma, draw it into an isolated channel on the bottom of the vacuum vessel, then pump it out of the machine. This is necessary because some ions escape from Alcator C-Mod's "magnetic bottle," and collide with the wall of the vacuum vessel, where they deposit their energy and become neutralized.

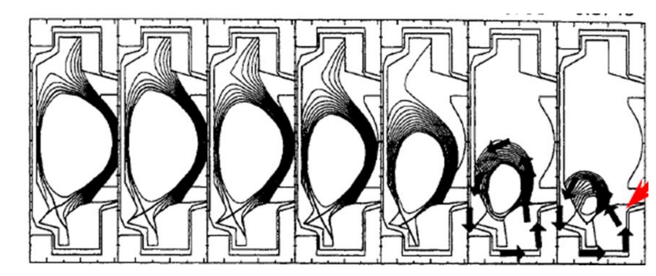


Fig. 4

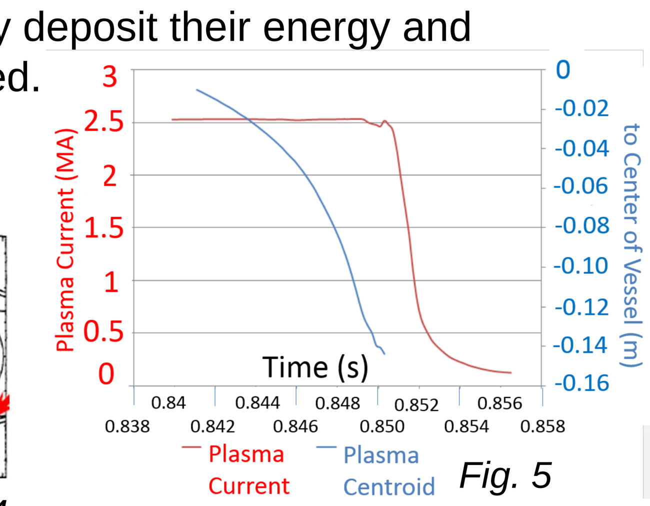


Fig. 5

All components in C-Mod must survive a disruption. A disruption is when the plasma suddenly collapses and loses all of its current. This rapid loss of plasma current, in C-Mod up to 2.5 MA, and position over 1 ms lead to rapidly changing magnetic fields and eddy currents in the metal structures in the vessel (such as the divertor). These eddy currents cross the magnetic fields produced by the plasma and coils resulting in large structural loads that the components must be able to withstand.

The current divertor in C-Mod, shown in photo, is not a continuous ring. This leads to high heat loads on the leading edges that face the plasma and also to large Lorenz forces due to eddy currents created during a disruption crossing the large toroidal field .

A new Advanced Outer Divertor has been designed for Alcator C-Mod that is electrically continuous with no leading edges. COMSOL was used to:

1. Predict the Magnetic Fields during a disruption for C-Mod using measured data to recreate and actual discharge.
2. Predict Eddy Currents and Loads in the divertor.
3. Calculate Stresses and Deflections due to those loads

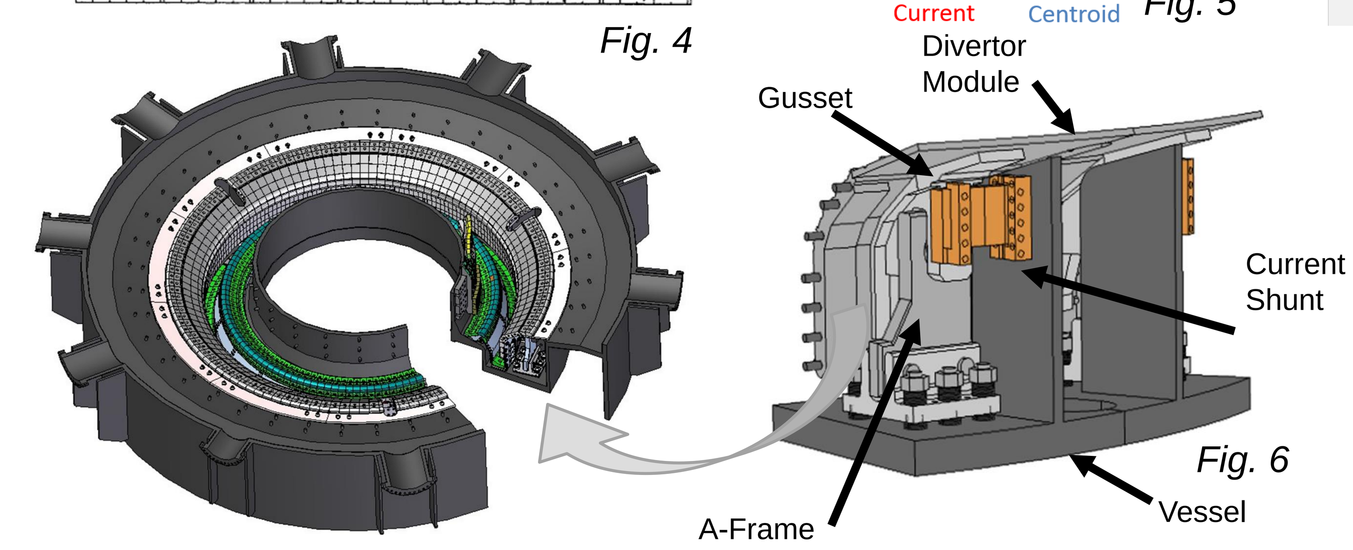


Fig. 6

Computational Methods

Fields are generated by currents in the plasma and in the magnetic coils in the vessel. The 'mf' physics interface is used to predict fields from these currents using a 36° cyclic symmetry model

PLASMA CURRENT

Up to 2.5 MA of current is driven in the plasma during a discharge.

This current flows in complicated patterns, so it is represented in the model by 24 current carrying filaments whose current is calculated by solving Maxwell's equations so that the field generated by the filaments equal the measured fields and fluxes generated by the plasma during the discharge.

COIL CURRENTS

There are 13 poloidal field (PF) coils and 1 toroidal (TF) in C-Mod. The currents measured in each of these coils during a discharge is input to the COMSOL model to predict the fields

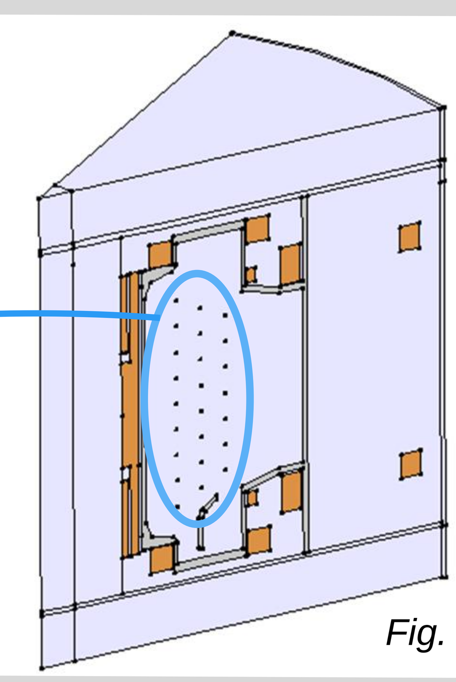


Fig. 7

Fields Predicted by 24 filament COMSOL model match accepted field reconstructions from EFIT

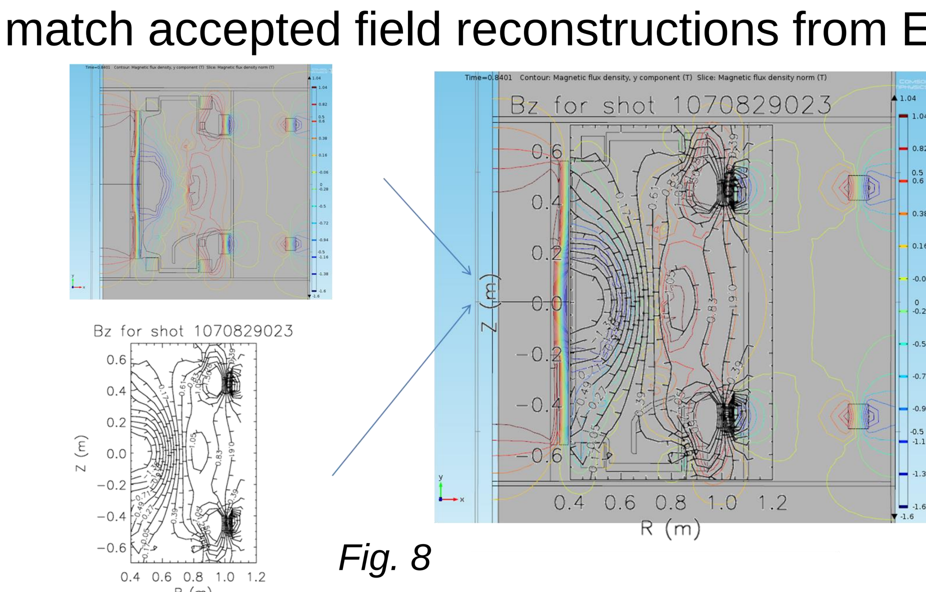


Fig. 8

Results

Fig. 9 RADIAL FIELD (T) PREDICTED BY COMSOL

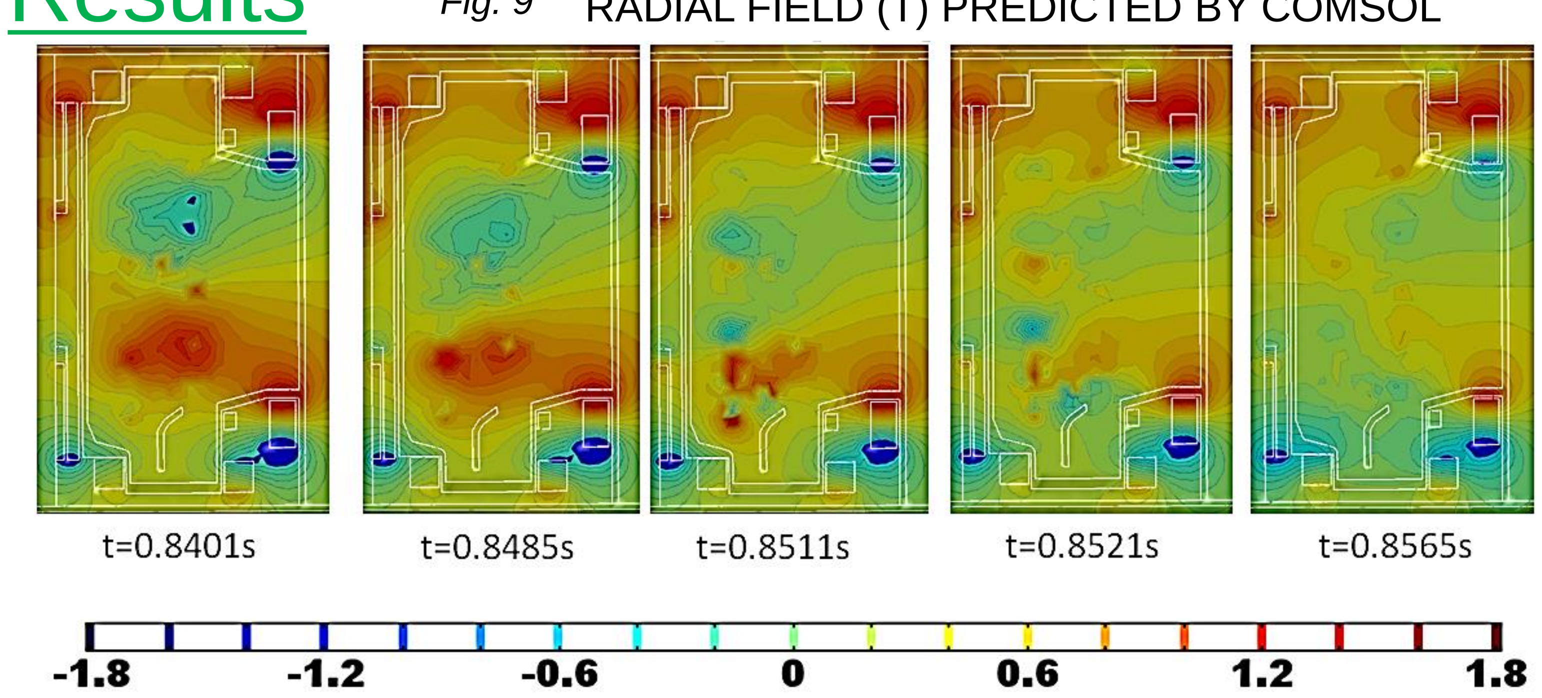
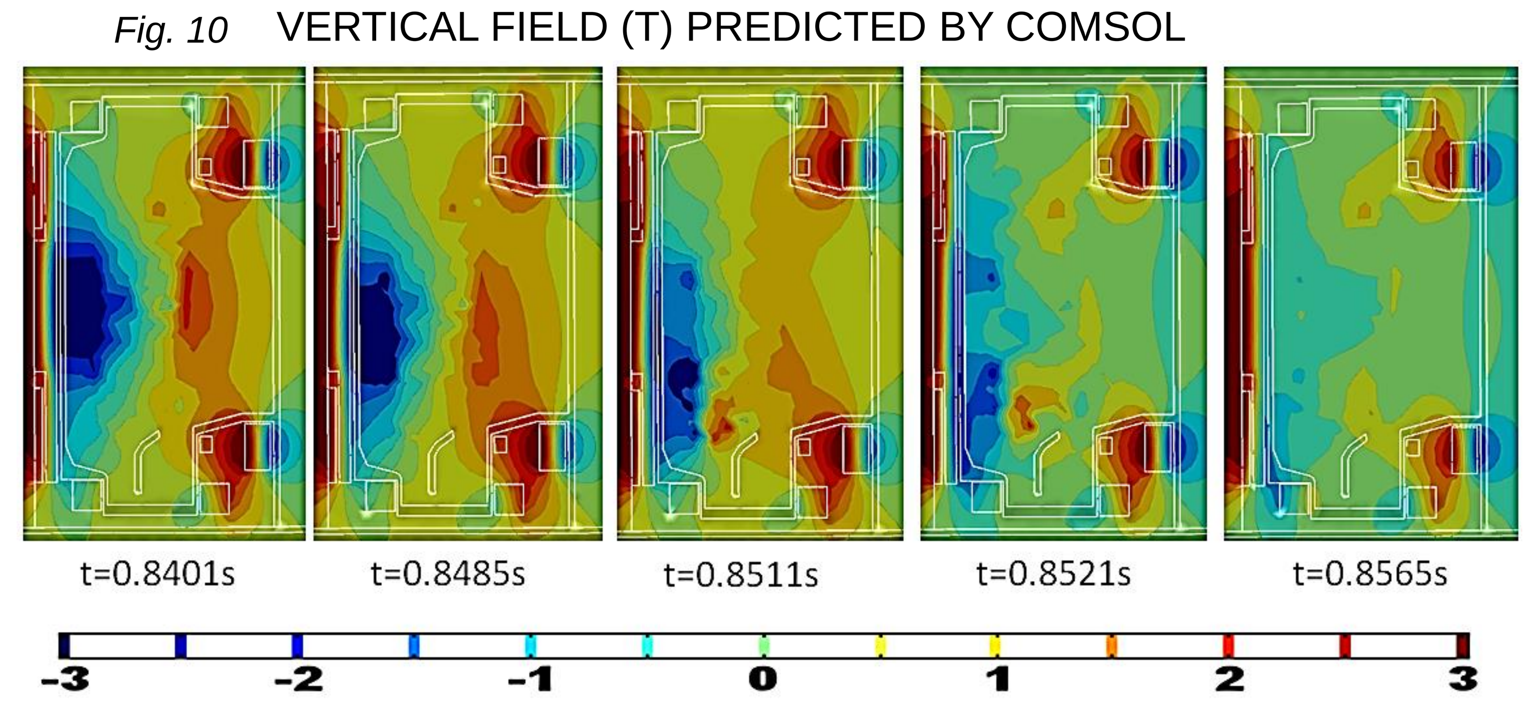


Fig. 10 VERTICAL FIELD (T) PREDICTED BY COMSOL



TOROIDAL FIELD (T) PREDICTED BY COMSOL

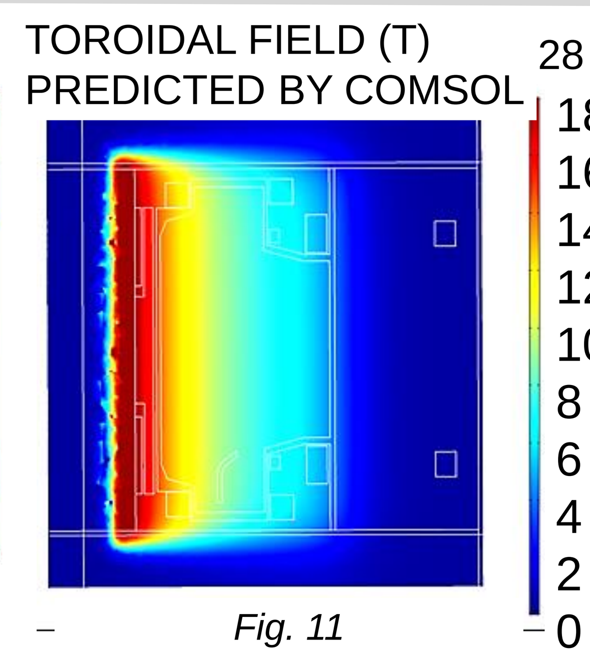


Fig. 11

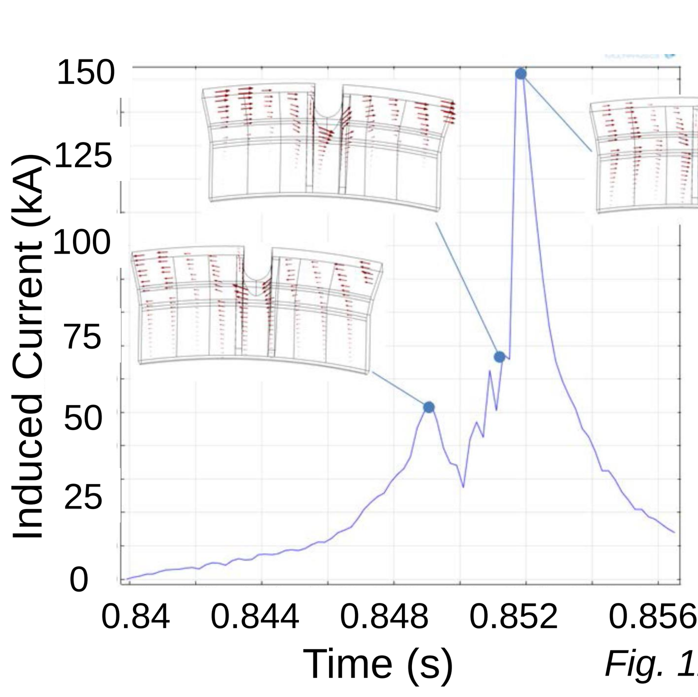


Fig. 12

Eddy Currents in Divertor during disruption travel toroidally. The eddy currents begin to rise as the plasma drops vertically, and then peak when the plasma current decays.

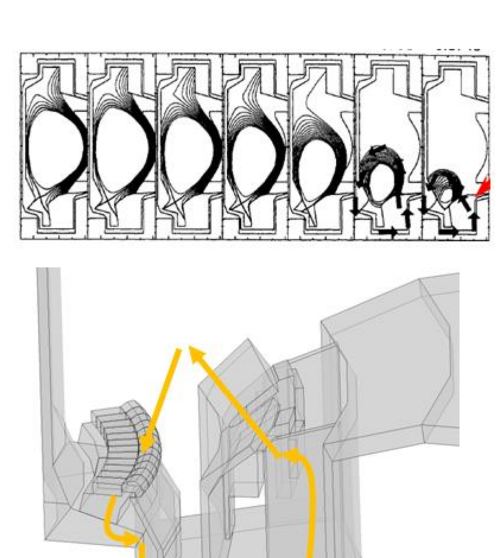


Fig. 13

Halo Current is current that leaves the plasma along open flux surfaces, enters the metal structure and then flows through the metal back into the plasma. In C-Mod, the halo current can be as high as 400 kA through a single module (200 kA through each shunt).

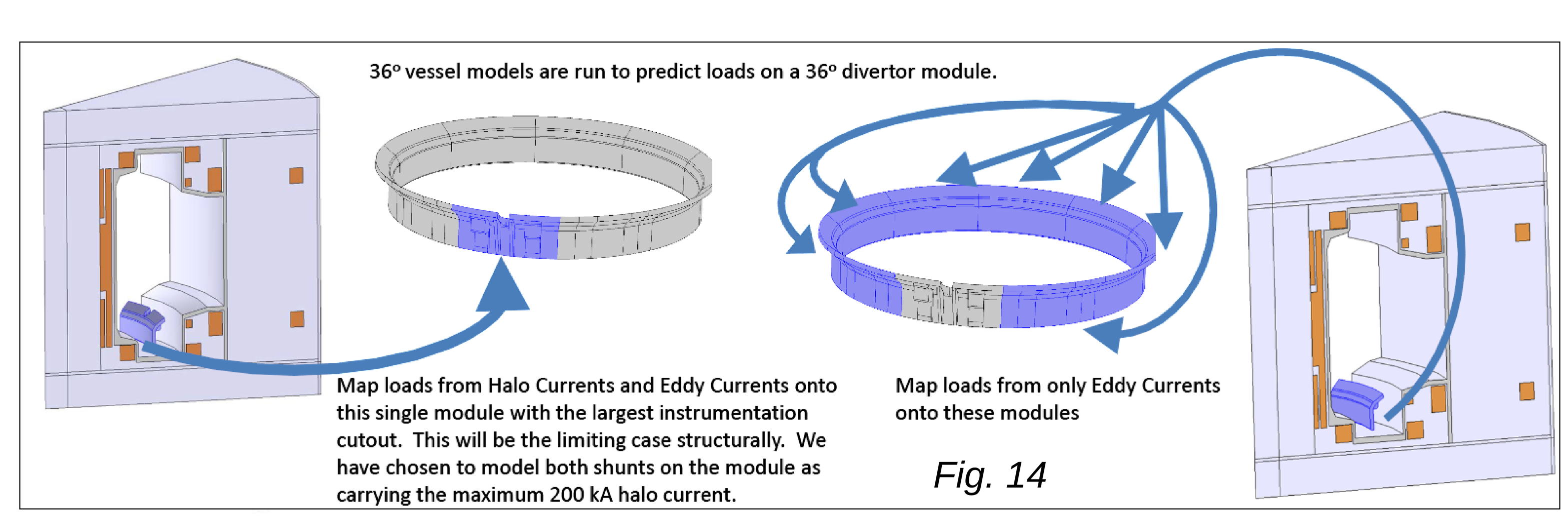


Fig. 14

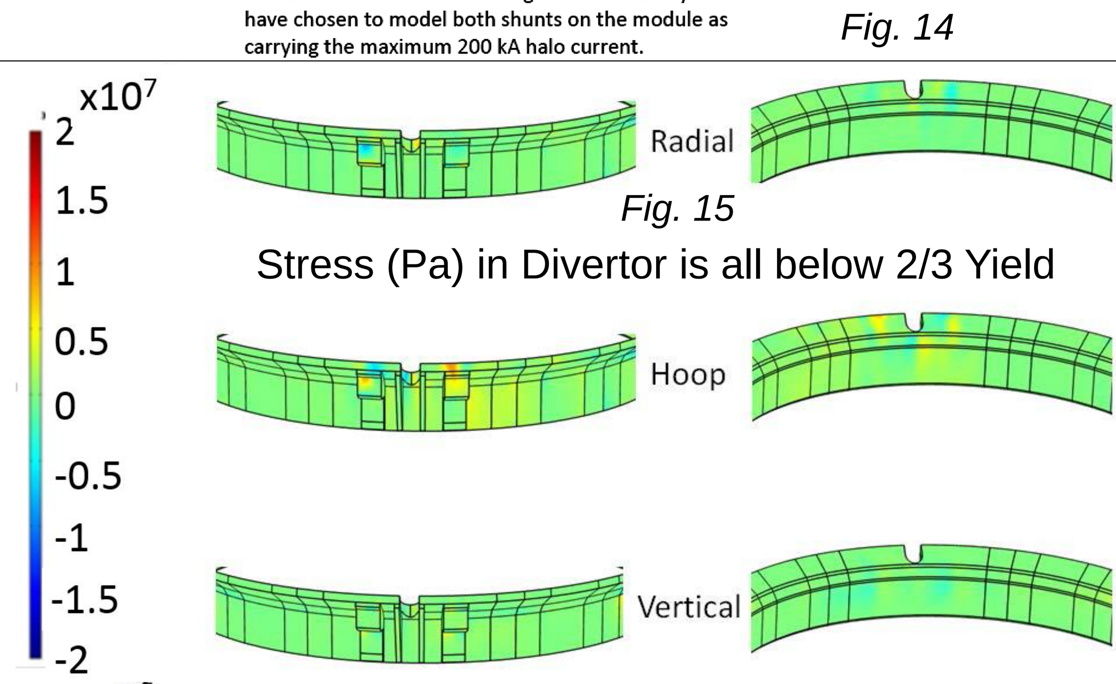


Fig. 15

Stress (Pa) in Divertor is all below 2/3 Yield

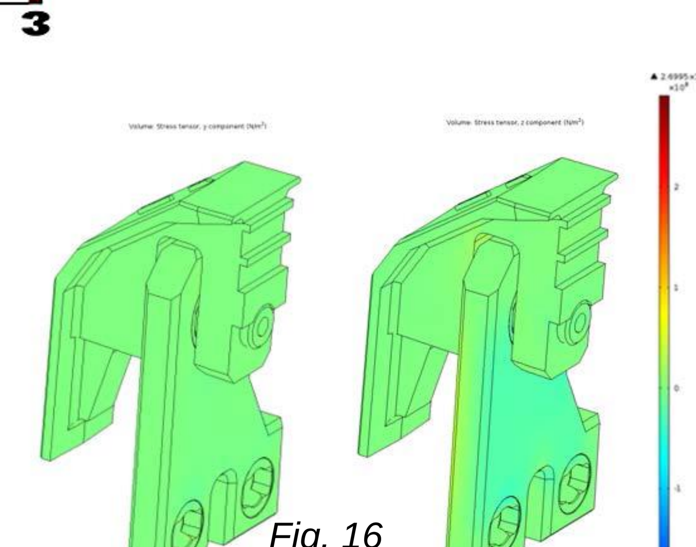


Fig. 16

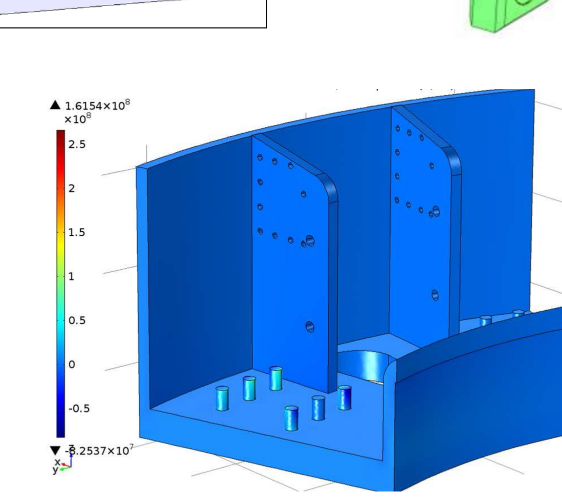


Fig. 17 Stress (Pa) in Vessel Studs is within allowable

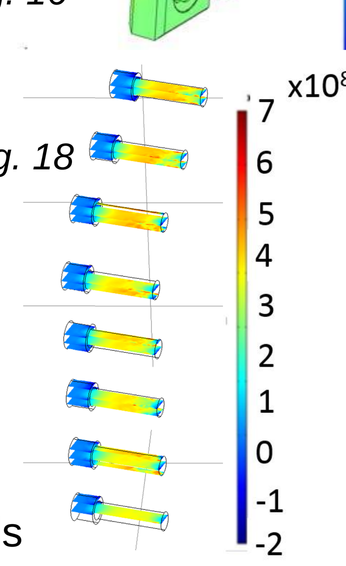


Fig. 18

Stress (Pa) in Bolts is below preload

Conclusions

The new electrically continuous divertor is successful in forcing the eddy currents to travel only in the toroidal direction so that they do not interact with the high toroidal field. This reduces the mechanical load on the divertor and it's components.

Stresses in all parts of the divertor are within allowable of 2/3 yield. The preload on the bolted connections between modules is high enough to withstand the asymmetric load from the halo currents.

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