Disruption modelling for JT-60SA

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Outline

Disruption simulations

- Introduction
- Scope

Available tools

- Symmetric disruptions
- AVDEs

Results

Conclusions & outlook

Introduction

If some of the operational limits are exceeded, a rapid growth of a MHD instability makes the plasma lose most of its thermal energy

- Thermal Quench (TQ): current density profile flattening, plasma current spike

Immediately after, the plasma cools down and its resistivity increases, so that the plasma current drops to zero

- Current Quench (CQ): on a time scale following empirical scaling laws

This may cause the vertical position feedback to lose control of plasma, giving rise to a Vertical Displacement Event (VDE)

- The plasma eventually hits the wall, injecting currents directly in the structures (halo currents)

In specific situations (e.g. q drops below a given threshold) the plasma kinks

- AVDEs (Asymmetric VDEs), toroidal peaking factor
- May give rise to sideway forces

Disruption mitigation system may be used

- They typically affect the parameters of the disruption (e.g. CQ time, toroidal peaking factor etc.)

Scope

Aim of disruption simulation reported here is to replicate/predict the plasma behaviour during a disruption in order to evaluate the loads on the structures

- Both symmetric and non-symmetric events

Possible indications (non exaustive list)

- Which is the growth rate of the vertical instability?
- Where is the neutral point?
- Which is the EM load on specific components?
- Which fraction of plasma current is injected in the structures as halo currents?
- Is disruption mitigation useful/necessary for EM loads?
- Which is the heat load on the wall? (global energy exchange, flux maps for detailed computations, etc.)

Other issues related to disruption modelling not addressed here

- Disruption mitigation physics: SPI vs. MGI etc.
- Disruption prediction: physics-based vs. AI-based
- Runaway electron physics: formation, energy deposition etc.
- Mechanical/structural modelling: from forces to stresses/displacements

3D meshing of JT-60SA

A detailed 3D mesh of the vacuum vessel has been produced

- Removing the passive plate, the main stabilizing effect is provided by vessel
- This is also needed for breakdown modelling activities (see Mattei's presentation Wed 17/3)

Problem: the vessel is not periodically symmetric

- Ports do not replicate with an exactly periodic geometry

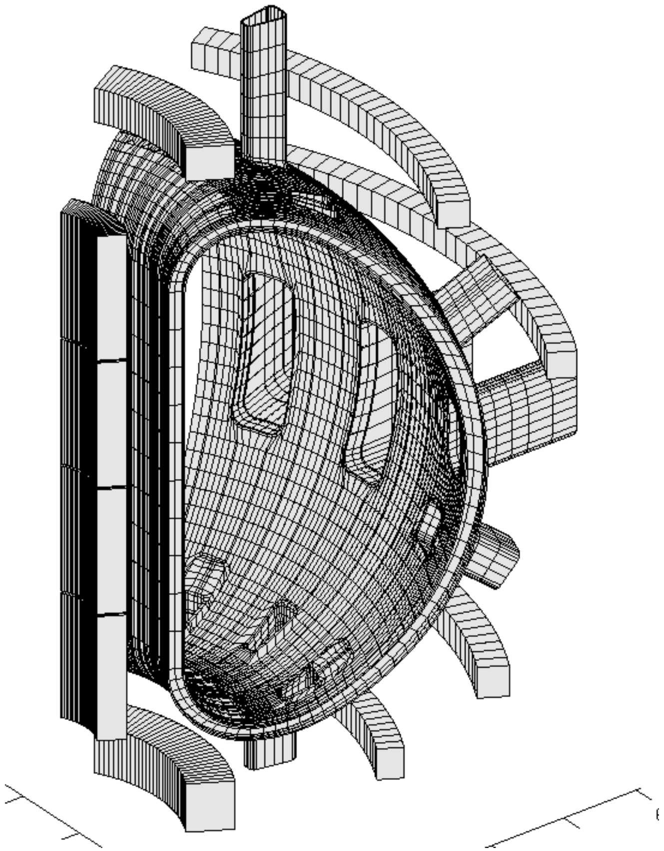
Approach used

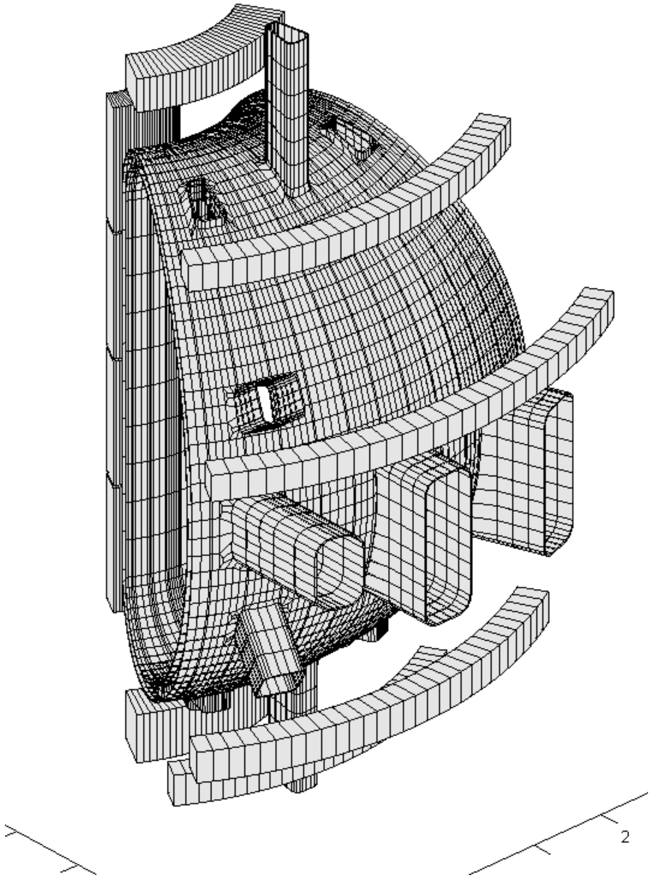
- One mesh covering 60° toroidally ("typical sector") and fictitiously replicated with rotational symmetry
- One mesh covering 360°, reproducing the actual situation

A mesh of the stabilizing plate also is available

- Not considered for IC-relevant activities

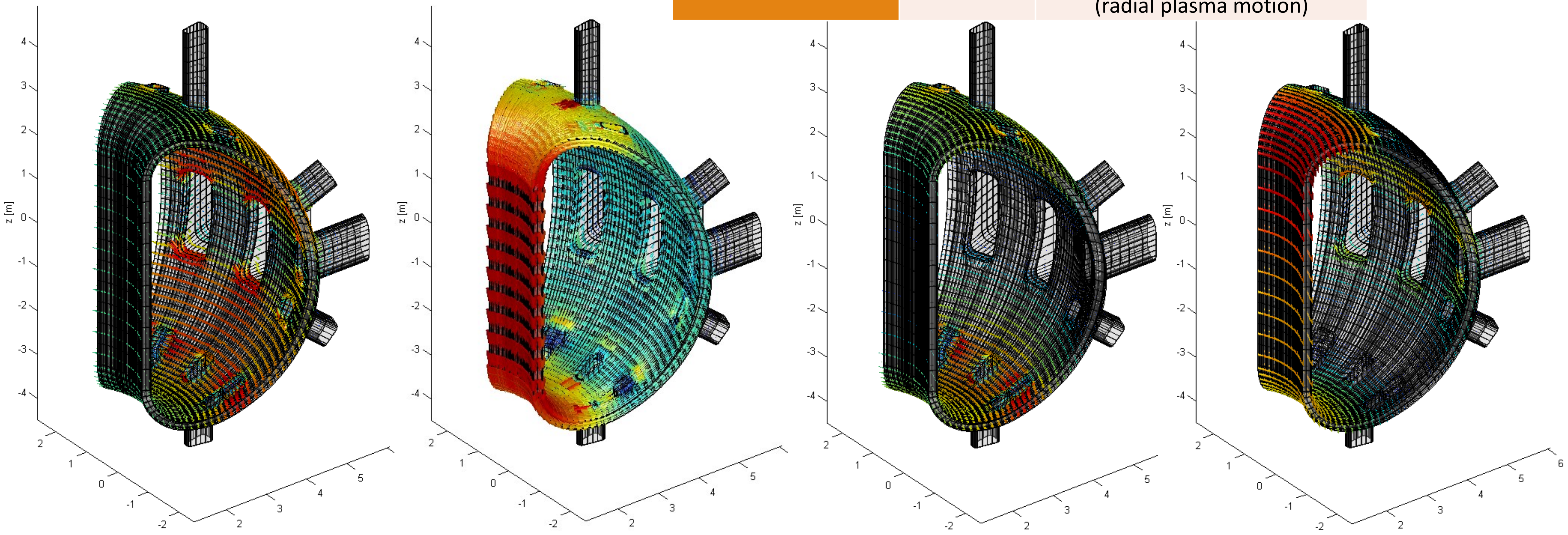
3D meshing



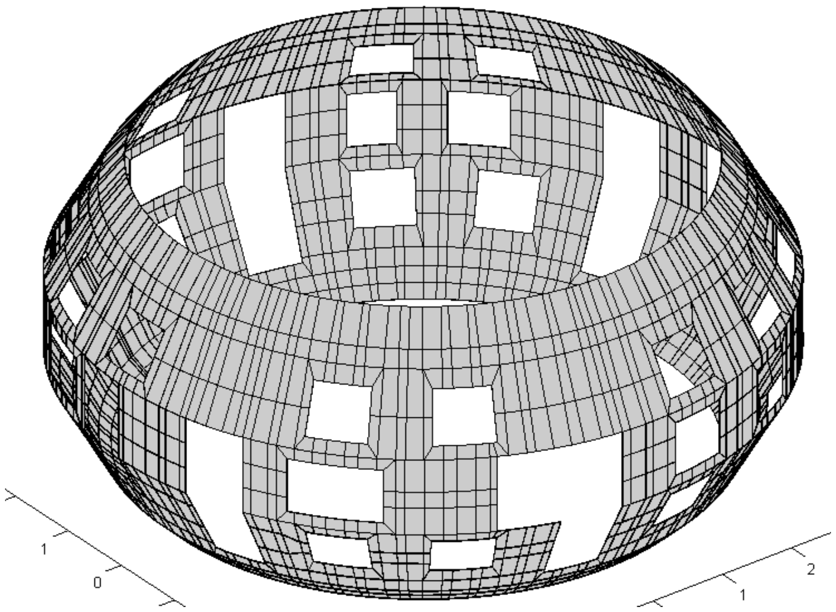


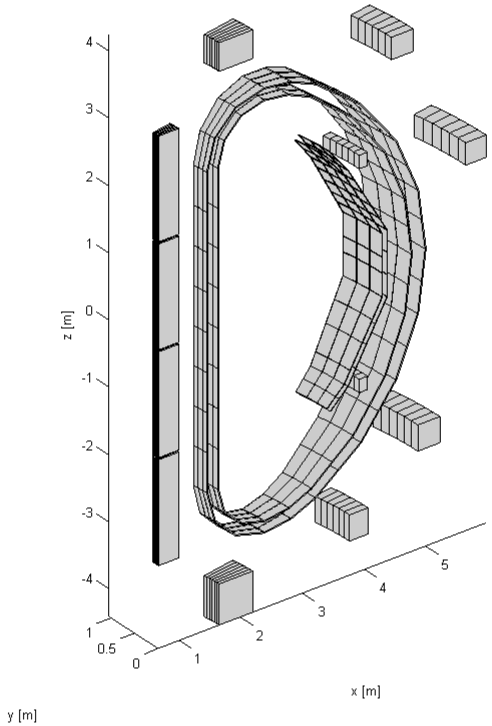
3D meshing

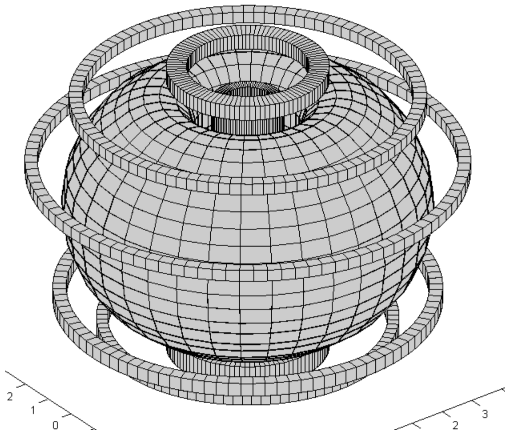
Time constant [ms]	Harm.	Notes
88.6 ms	n=0, m=0	Toroidally directed current
80.7 ms	n=0, m=0	Poloidally directed current
53.9 ms	n=0, m=1	Up-down antisymmetric (vertical plasma motion)
35.6 ms	n=0, m=1	Inboard outboard antisymmetric (radial plasma motion)



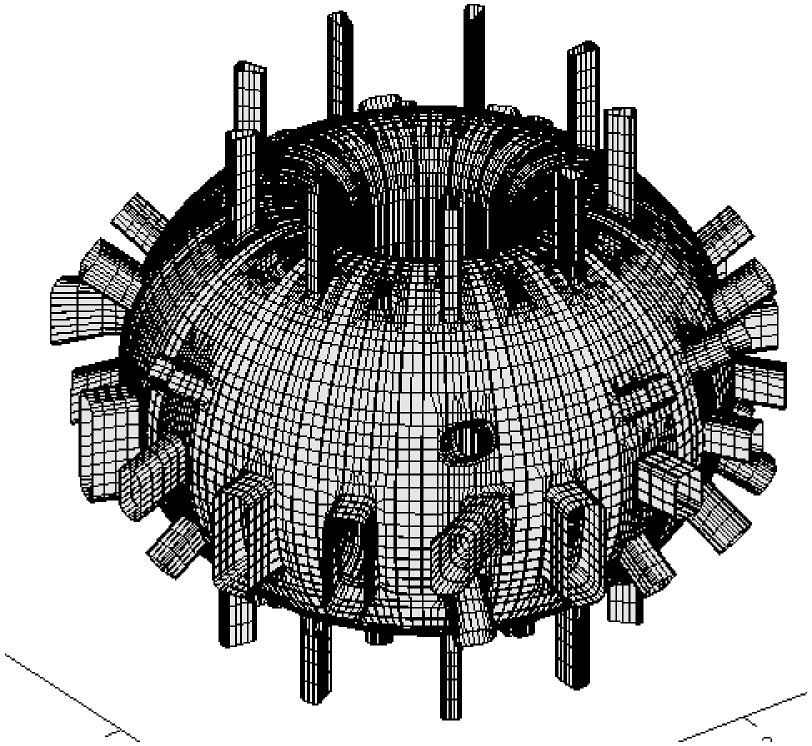
3D meshing

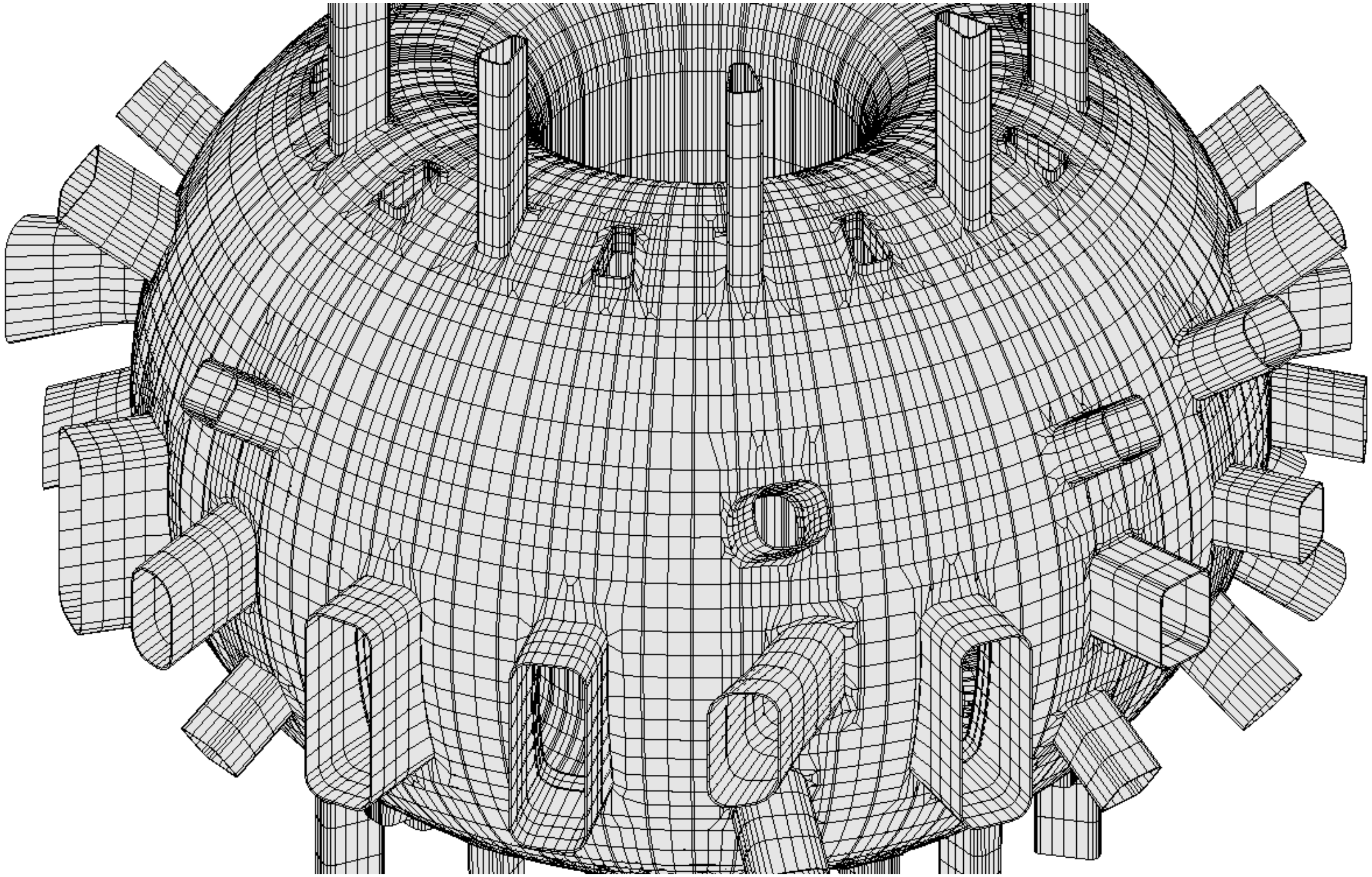




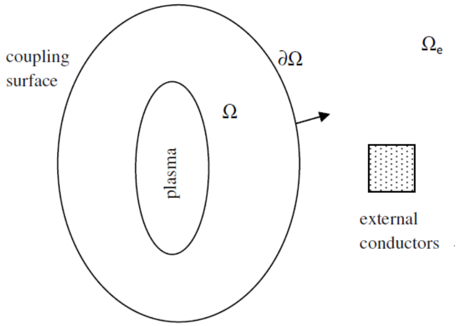


3D meshing





Symmetric disruptions



Inside Ω: plasma evolutionary equilibrium

Outside Ω: eddy currents in 3D structures

On ∂Ω: suitable coupling conditions

CarMa0NL: able to describe the evolutionary equilibrium of axisymmetric plasmas, in presence of three-dimensional volumetric conducting structures

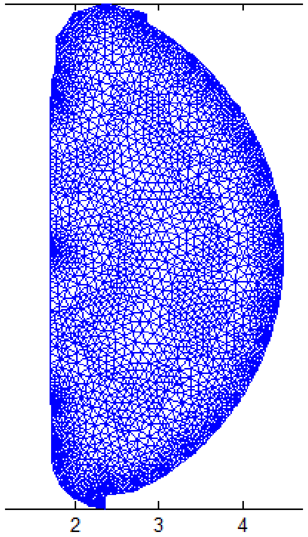
Time scale of interest is supposed much longer than Alfvèn time

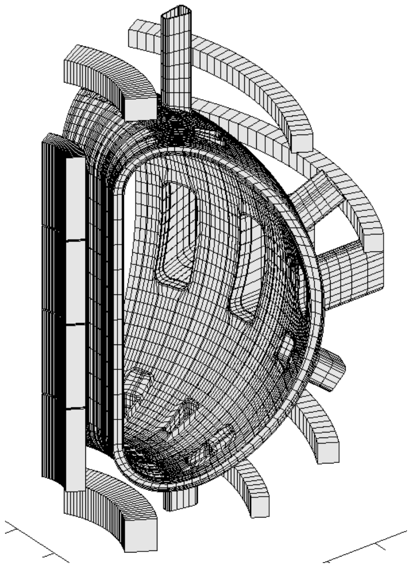
- Plasma mass can be neglected
- Plasma moves through equilibrium states

The formulation uses a coupling surface to describe the electromagnetic interaction between the plasma and the conductors

- The most convenient formulation can be used in each domain

F. Villone et al., Plasma Phys. Control. Fusion 55 (2013) 095008





3D effects on VDE growth rates

Growth rates (s^{-1}) under different assumptions and with different codes

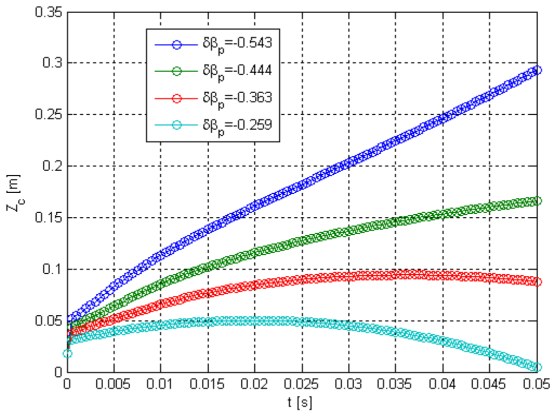
- Good agreement between CarMa0NL and CREATE_L on axisymmetric meshes
- The 3D effect on growth rate is detrimental and in the range of 10% - 20%;
- The effect of the superconducting PF coils on the growth rate is very significant

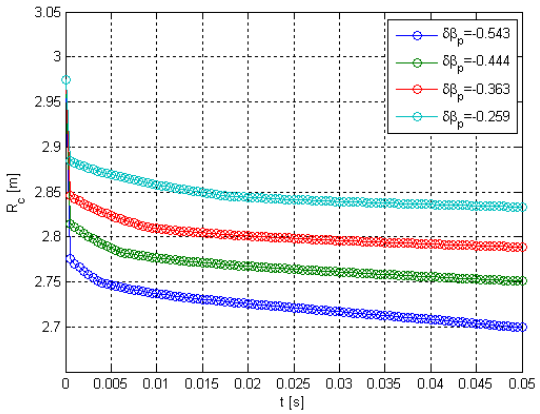
Code	Mesh	Config. A	Config. B	Config. C
CREATE_L	2D - only passive	24.3	19.1	17.8
CarMa0	2D - only passive	24.6	19.4	18.3
CarMa0	3D - only passive	28.8	23.1	21.4
CREATE_L	2D - active + passive	8.35	4.60	3.89
CarMa0	2D - active + passive	8.32	4.95	4.31
CarMa0	3D - active + passive	9.22	5.47	4.68

Beta drop recovery studies

Best Achievable Performance: maximum beta drop which can be "recovered" by a voltage step in the control coils

- Beta drops in the range of 0.4 - 0.5 may be recovered within the limits assumed on power supplies
- More optimistic results are obtained with a 2D mesh, due to slower growth rate

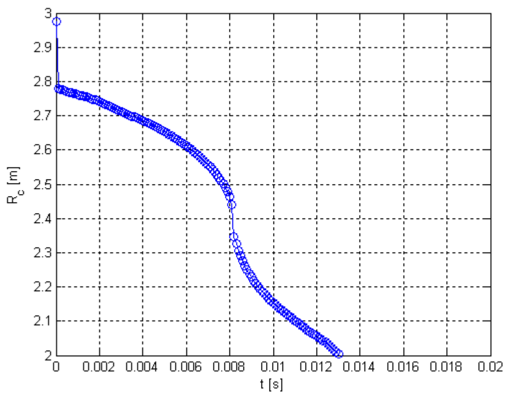


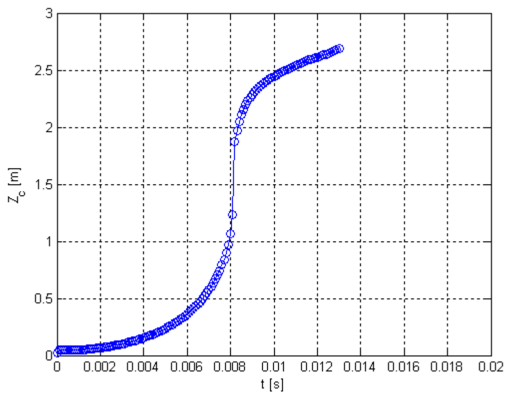


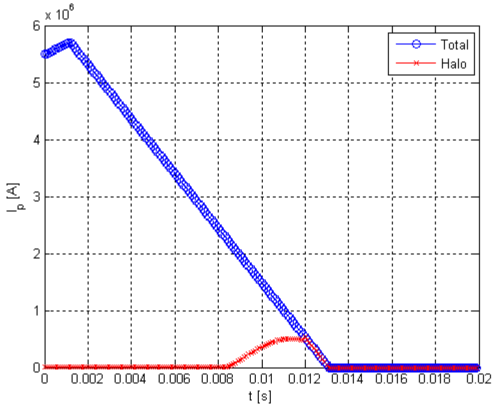
F. Villone and S. Mastrostefano, "Nonlinear modelling of the effects of plasma perturbations in tokamaks," IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society, Florence, Italy, 2016, pp. 6370-6374

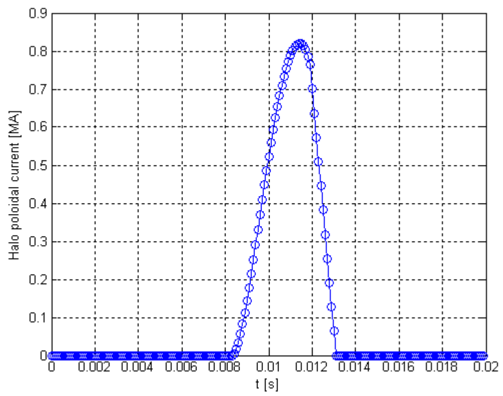
Disruption simulations

Major disruption including stabilizing plate [G. Giruzzi, Nucl. Fusion 57 (2017) 085001]









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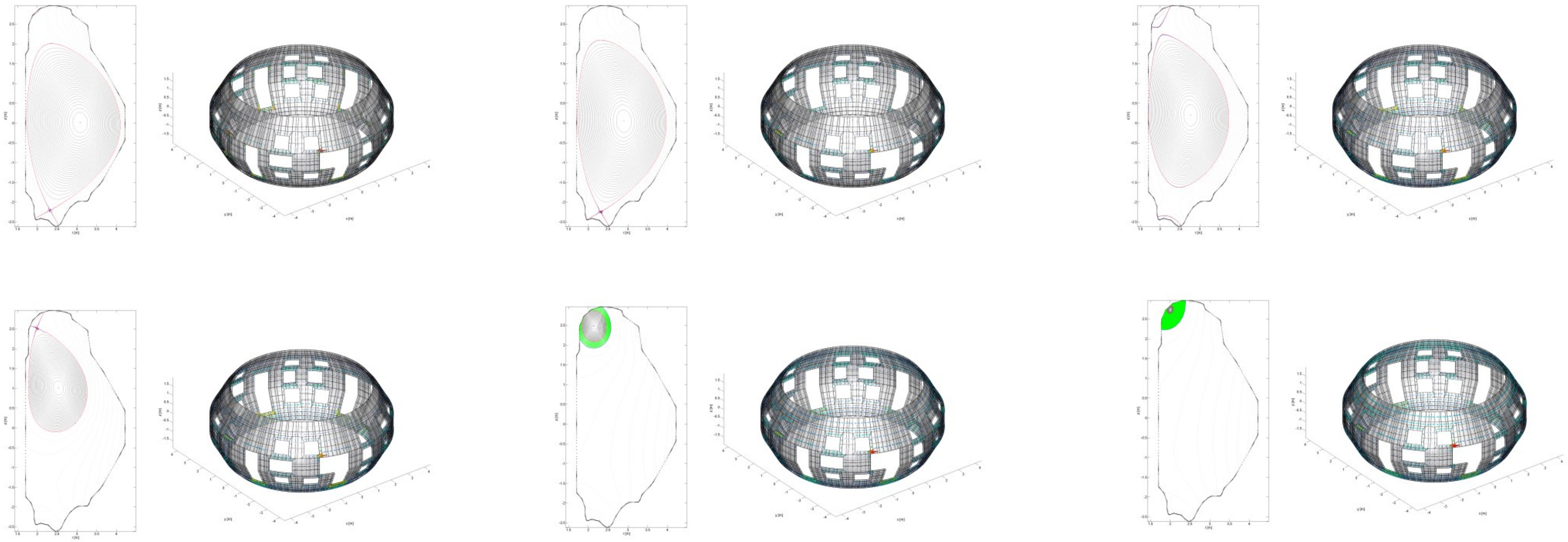
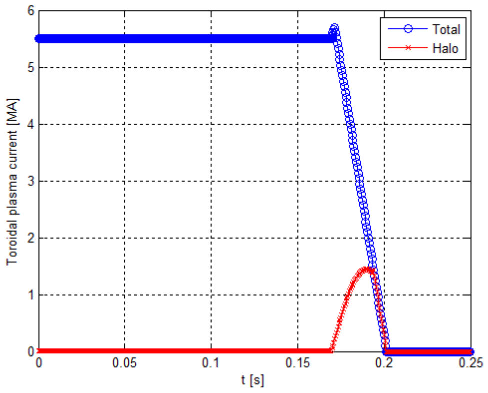
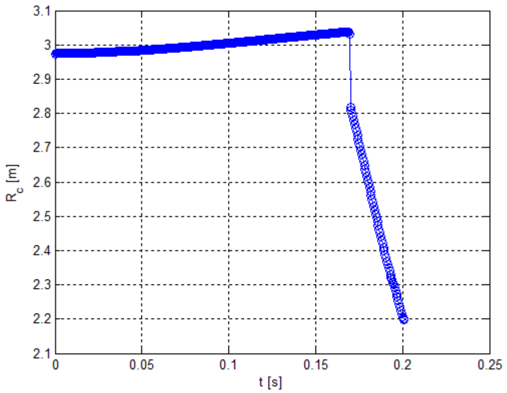
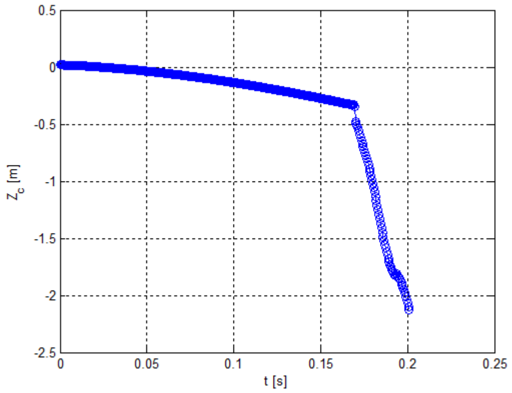


Disruption simulations

Downwards VDE including stabilizing plates [G. De Tommasi et al., IAEA 2018]







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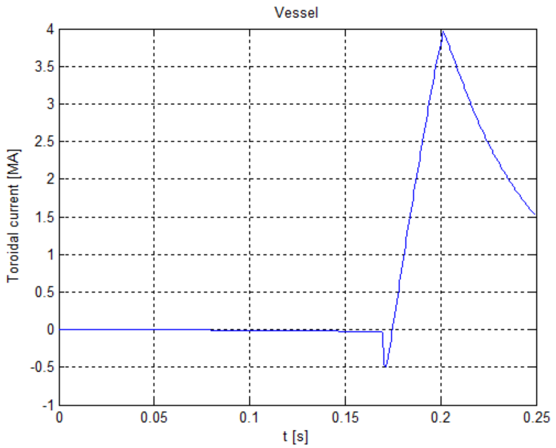
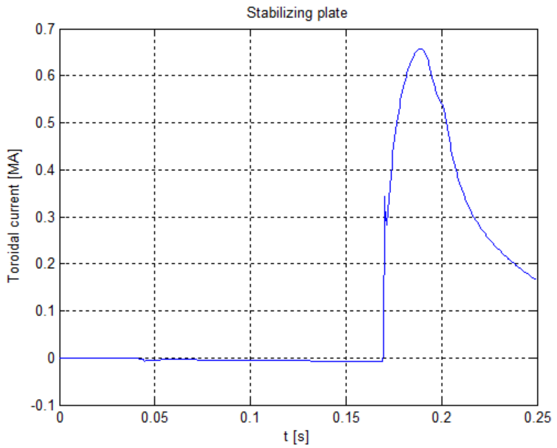
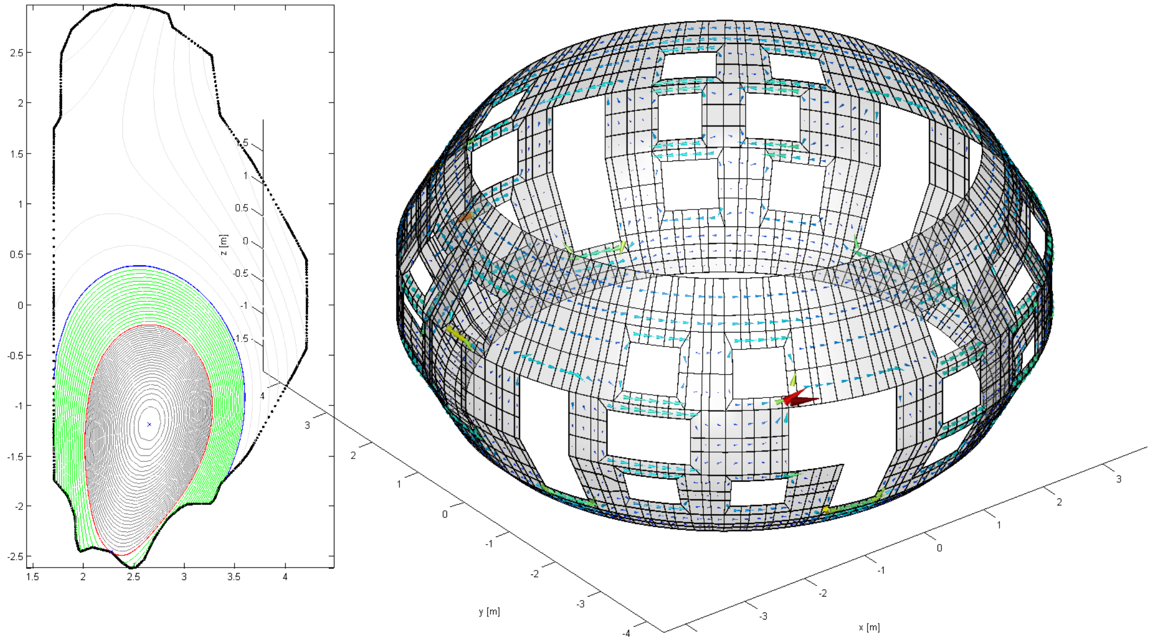
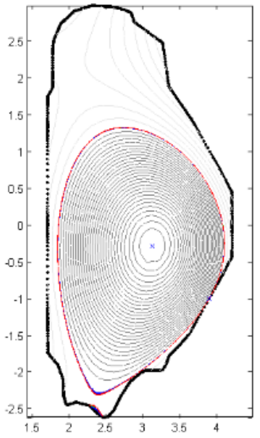


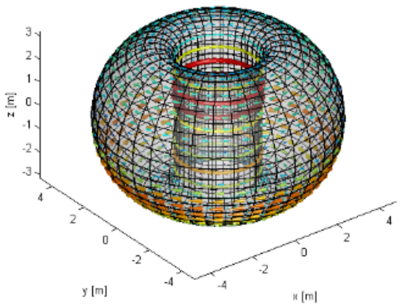


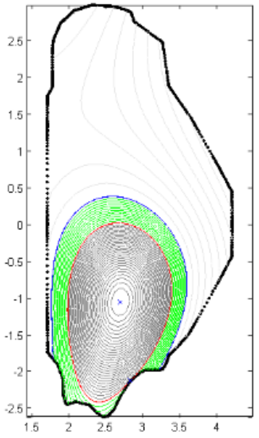


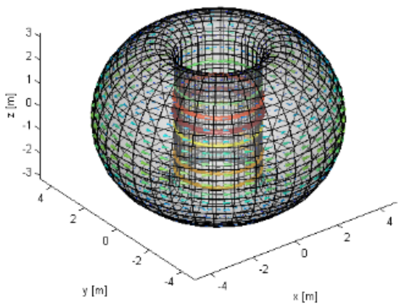
Disruption simulations

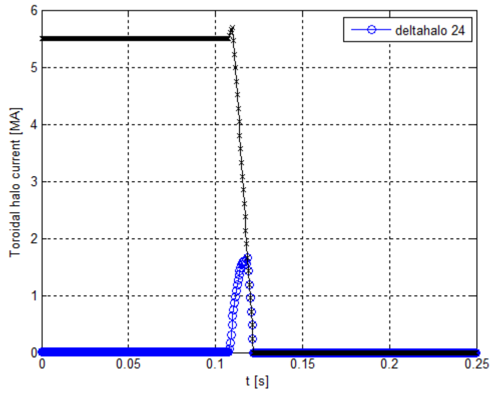
Downwards VDE without stabilizing plate [G Giruzzi et al 2020 PPCF 62 014009]

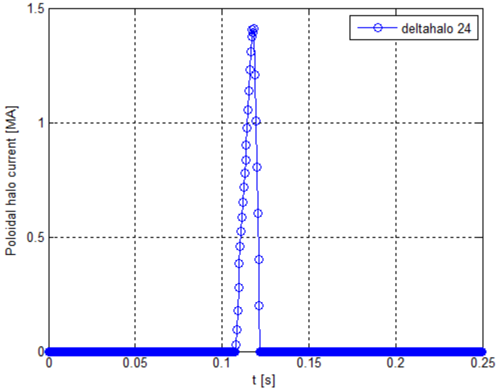










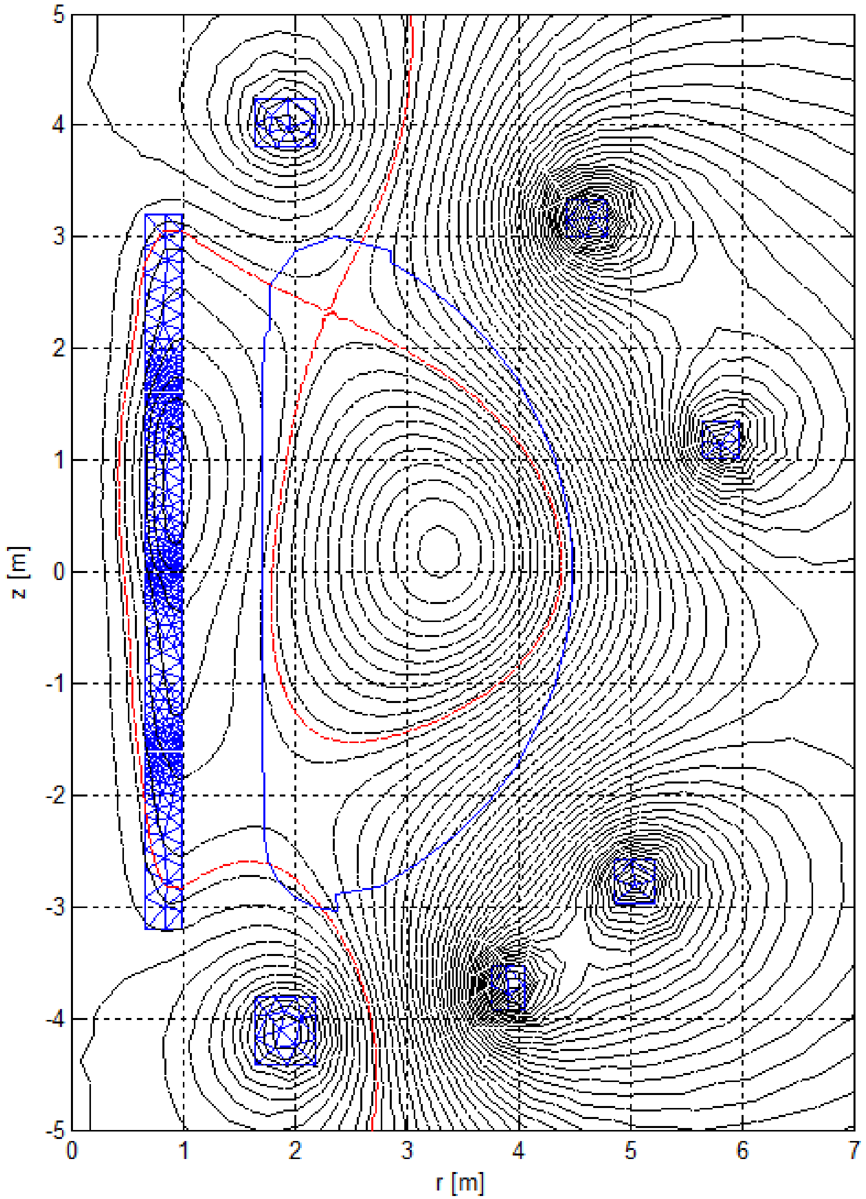


Disruption simulations

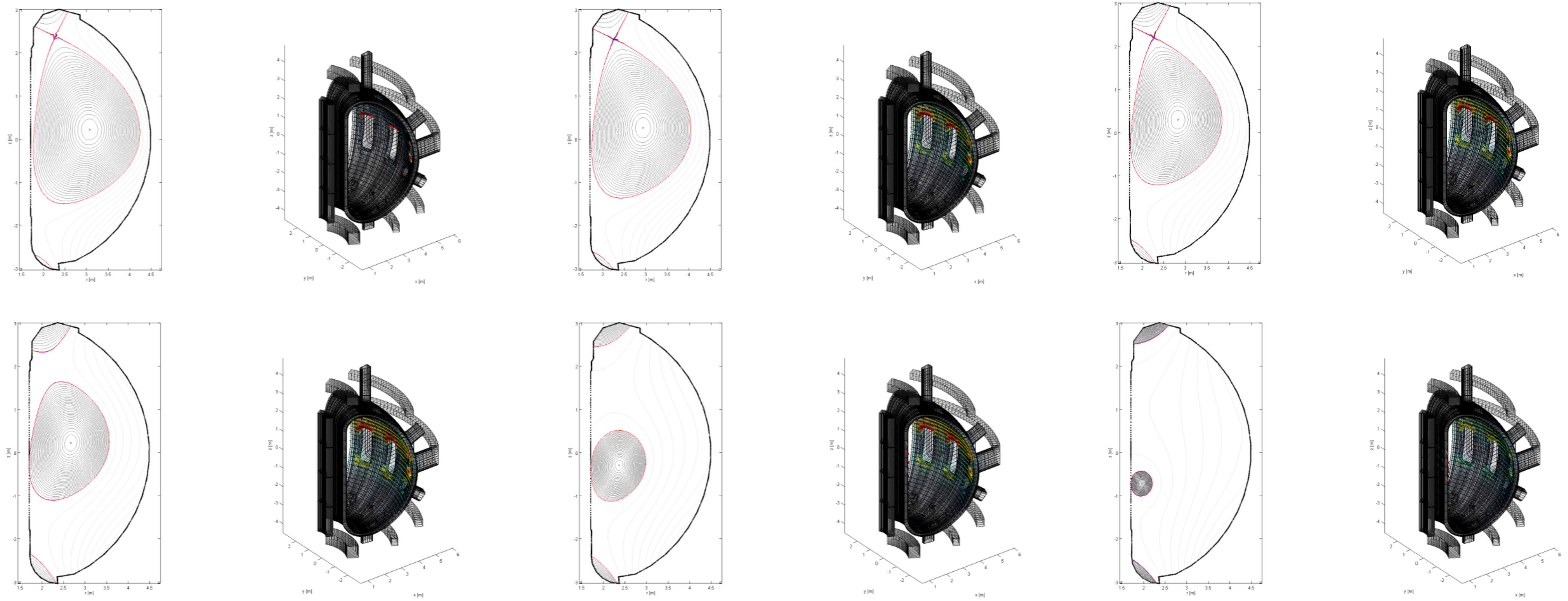
Starting equilibrium configuration:
Upper Single Null, high beta

I_p = 1.000 MA
β_p = 0.666
l_i = 0.833
major radius R = 3.082 m
minor radius a = 1.304 m
elongation κ = 1.478
triangularity δ = 0.522
Upper triang. δ_U = 0.603
Lower triang. δ_L = 0.442

Upper point = 2.296 m, 2.330 m
Lower point = 2.505 m, -1.525 m
Outer point = 4.386 m, 0.085 m
Inner point = 1.778 m, -0.296 m
Magnetic axis = 3.291 m, 0.180 m
Current centroid = 3.174 m, 0.203 m
Aspect ratio R/a = 2.363



Disruption simulations



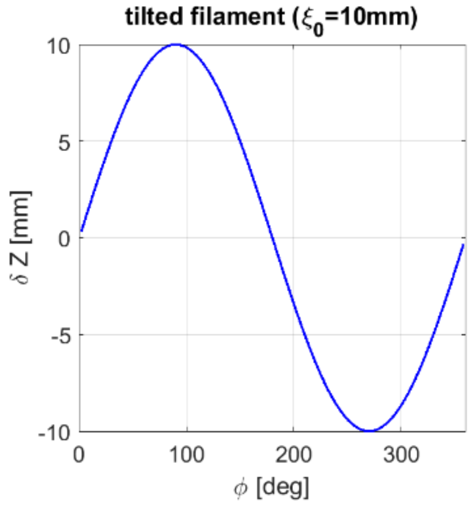
AVDEs modelling

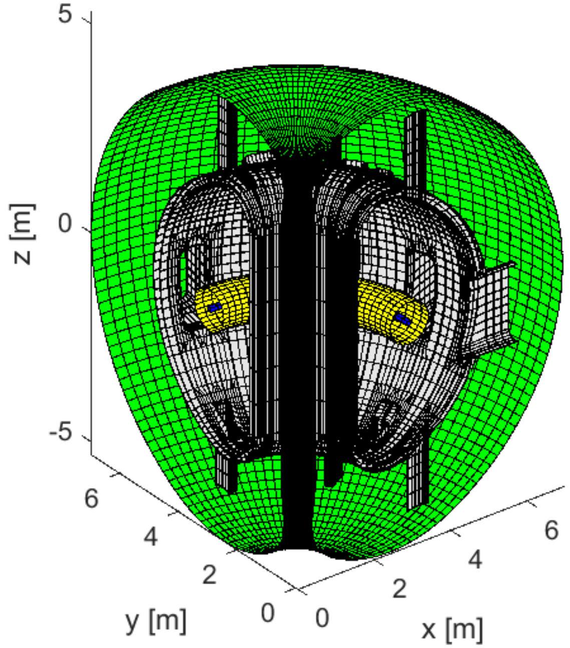
Sideways force induced by a simplified n = 1, m = 1 kink perturbation

- Time varying tilt + horizontal displacement of a single axisymmetric filament

Mesh covering 360° (only 90° shown for clarity)

- Inner and outer surfaces used for Maxwell stress tensor computations



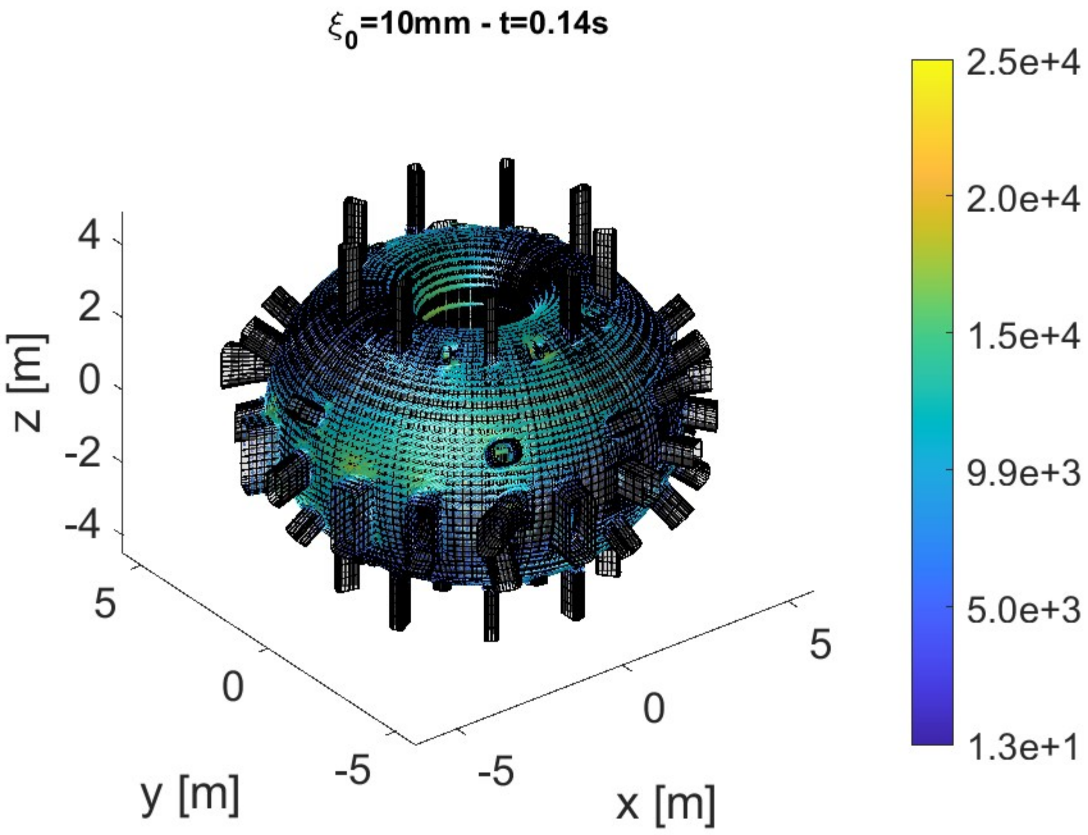


AVDEs modelling

Eddy currents pattern induced by filament tilt

No halo currents considered in this computation

[F. Villone et al., report SA-O.A08-T002-D005, Dec. 2020]

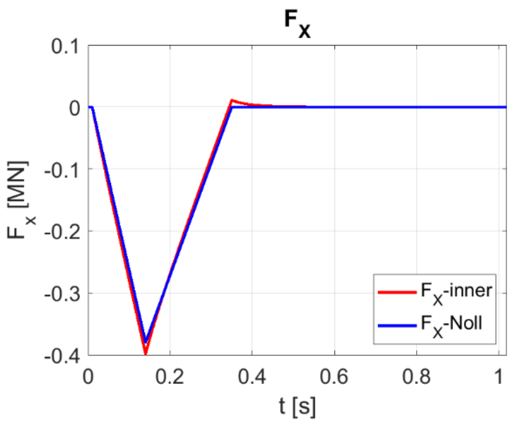


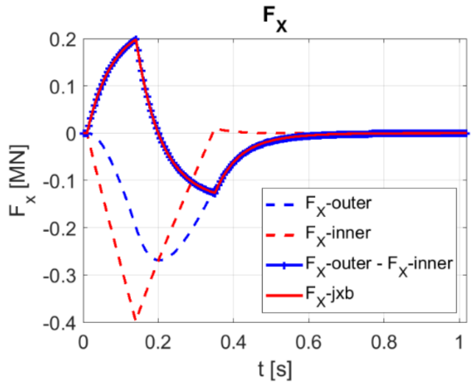
AVDEs modelling

The filament is not in equilibrium
- Sideway force acting on the filament
- Positive comparison with Noll's formula

Sideway force on vessel
- Of the order of 100 kN for the given displacement (5 mm radially, 10 mm vertically)
- Confirmed by Maxwell stress tensor computation

Assuming the plasma in equilibrium, the sideway forces may be significantly lower [F. Villone, report SA-M.A01-T003-D005, Dec 2019]





Conclusions

Disruption modelling for JT-60SA up and running

Several results produced along the last years

Both symmetric and asymmetric events covered

Detailed mesh available

Geometries/configurations relevant for IC and early phases addressed

Outlook

- Further disruption simulations (symmetric & asymmetric) (to be agreed)
- Synergy with breakdown studies
- Compare to / validate with experimental data
- Coupling with mechanical models/measurements

Thank you for your attention

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