Modelling and control of RFX-mod tokamak equilibria

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Summary

- **RFX-mod device** can be operated as:
  - Reversed Field Pinch
  - **Low current Tokamak** (Bt ~ 0.55 T, Ip ~150 kA @ qa ≈2)
  - Circular and non circular equilibrium configurations (Single Null and Double-Null) has been successfully achieved
    - These elongated configuration exhibit the **VDE instability** (**Vertical Displacement Event**, n=0 Resistive Wall Mode) which must be controlled

Thesis purpose

- Modelling of plasma-conductors-controller system of RFX-mod Tokamak configurations with increasing complexity:
  - ***2D linearized models***: *CREATE_L*
  - ***3D linearized models*** : *CarMa0*
  - ***3D nonlinear models*** *CarMa0NL*
- Theoretical and numerical advances (perspective):
  - Development of **Halo currents models**
  - Development of **3D equilibrium solvers**

2DLinearized model: CREATE_L [4]

- Main application: linearized model for control of current position and shape
- Assumptions:
  - Axisymmetric system
  - Massless plasma: timescale of the VDE dynamics is determined by the wall time
    - Plasma at each moment in equilibrium perturbed by the VDE, evolving with the mode developing
  - Plasma current density profile related to global parameters: (I_p, β_p, l_i, q_0)
  - Disturbances in terms of poloidal beta β_p and internal inductance l_i

- Single Null shot *Ip*=50 kA, *Bt*=0.55 T equilibrium data have been derived and used to produce the linearized plasma response model [1].
- Dynamical model characterized by 194 states (active + passive currents)
- Poloidal and inner equatorial **cuts in the shell** has been taken into account by imposing that their total current be null
- A **vertical instability n=0 is exhibited** by the model with slow growth rate (<10 s^{-1}), consistent with the experimental evidence [2].
- Comparison of *CREATE_L* and *MAXFEA* outputs in terms of equilibrium values of magnetic fields at sensors shown in *Tab.1* and *Fig. 1*

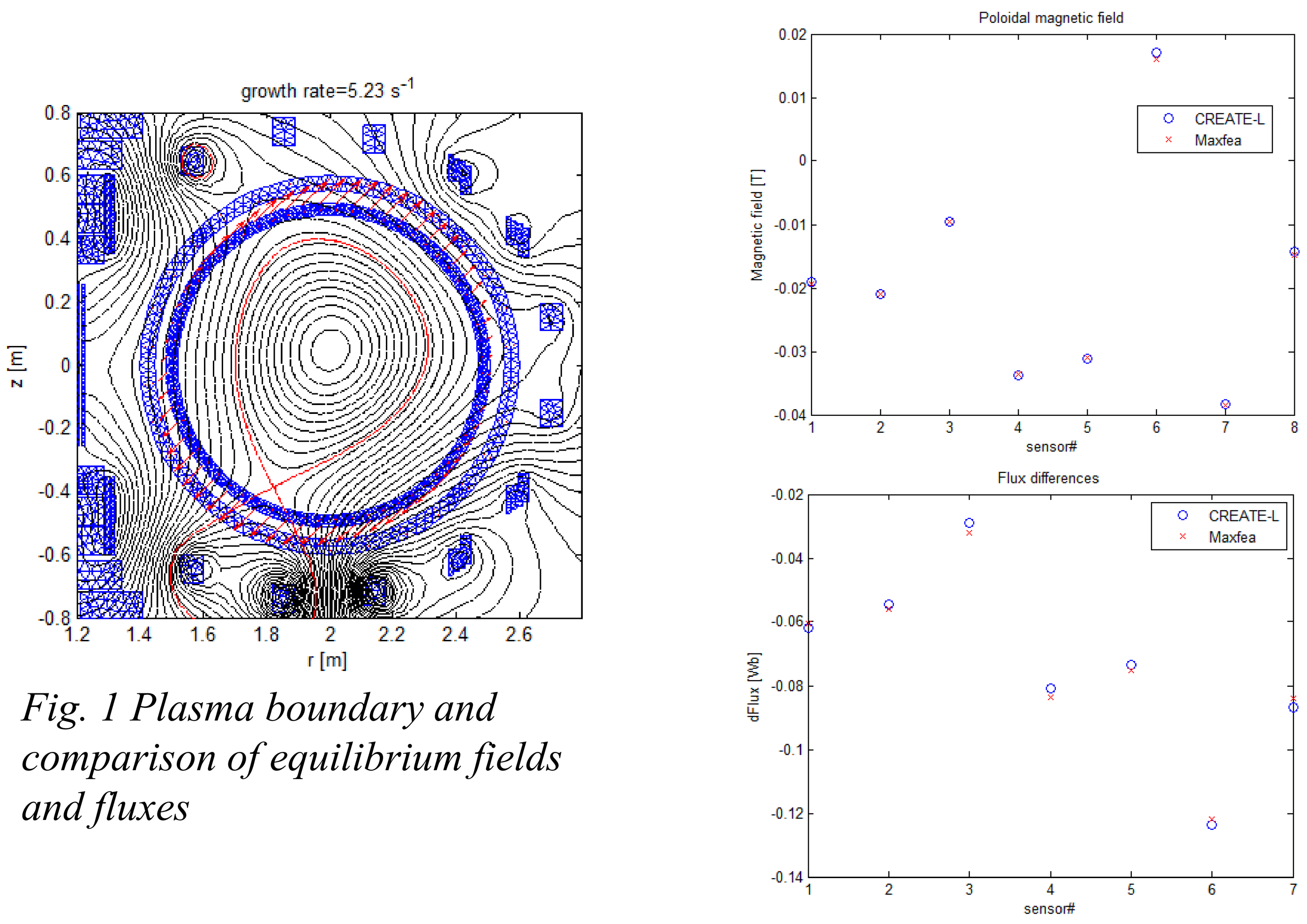


Fig. 1 Plasma boundary and comparison of equilibrium fields and fluxes

	l_i	β_p	$R_{X\text{-point}}$ [m]	$Z_{X\text{-point}}$ [m]
CREATE_L	1.04	0.102	1.822	-0.387
MAXFEA	1.06	0.111	1.827	-0.384

Table 1. Plasma equilibrium values computed by CREATE_L and MAXFEA

3D NON-LINEAR MODEL:CARMA0NL [6]

- The code is able self-consistently solve nonlinear evolutionary axisymmetric equilibrium equations inside the plasma, coupled to eddy current equations in 3D volumetric conductors. , through Newton-Raphson iterations.
- Study situations such as disruptions, ELMs, limiter-diverted transitions, current quenches, etc.
- Input: time evolution of internal inductance l_i and poloidal β_p

- A fictitious linear **plasma current quench** event has been considered with *CarMa0NL*: a typical current density pattern and the corresponding plasma configuration are reported in *Fig. 3*.

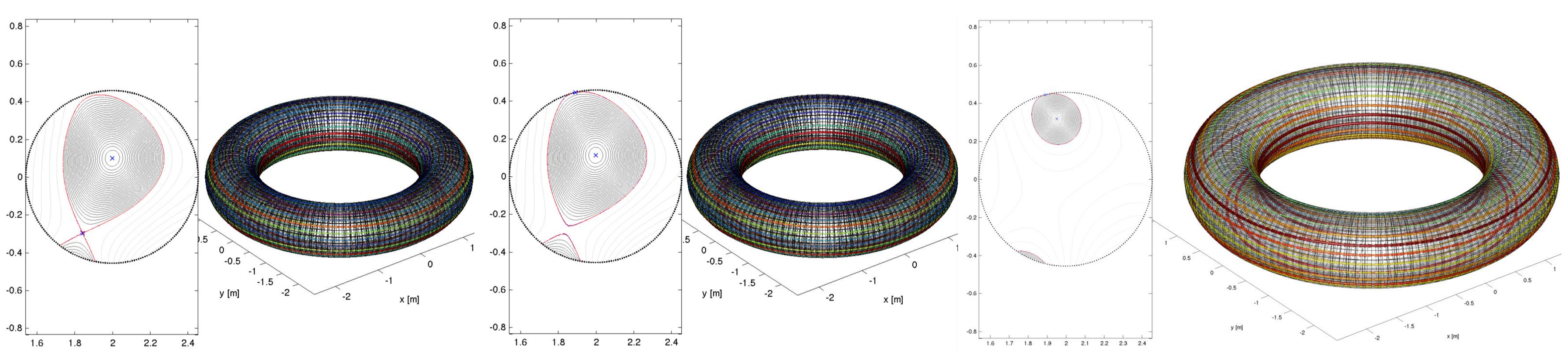


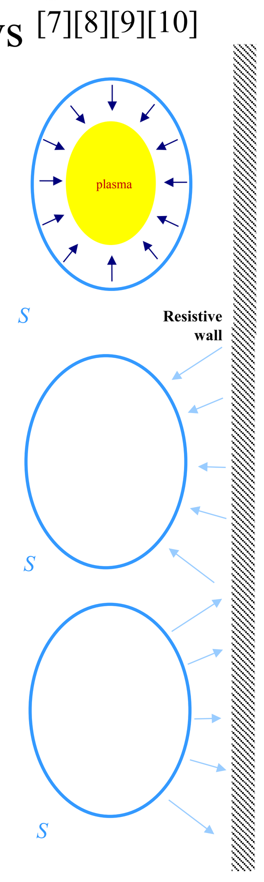
Fig. 3 Plasma configuration and current density patterns

3D LINEARIZED MODEL: CARMA0 [5]

Self-consistently coupling of:

- Linearized plasma response model (as *CREATE_L*)
- 3D time-domain eddy current integral formulation (*CARIDDI*)

A surface *S* is chosen in between the plasma region and the conducting structures through which the interaction can be decoupled as follows [7][8][9][10]



- The plasma (instantaneous) response to a given magnetic flux density perturbation on *S* is computed as a plasma response matrix.
- Using such plasma response matrix, the effect of 3D structures on plasma is evaluated by computing the magnetic flux density on *S* due to 3D currents.
- The currents induced in the 3D structures by plasma are computed via an equivalent surface current distribution on *S* providing the same magnetic field as plasma outside *S*.

- The RFX-mod **3 mm thick shell**, clamped over the vacuum vessel, provides the **main stabilizing contribution** (*Table 2*) and is characterized by poloidal and inner equatorial gaps, which has been accurately reproduced in the 3D realistic mesh; the toroidal support structure has been neglected.

	CREATE_L	CarMa0 (3D axisymm.)	CarMa0 (3D realistic)
γ_{tot} [s^{-1}]	7.36	7.33	7.55
$\gamma_{vessel\ only}$[s^{-1}]	335.4	334.2	N.A.

Table 2. Comparison of growth rates

- A fictitious 3D axisymmetric mesh has been generated and used in computations in order to provide a reference and a cross-check with axisymmetric models for the entire procedure.

  In this case, the modified inductance matrix *L** computed over the 3D axisymmetric mesh by *CarMa0* has been compared with the *CREATE_L* results, providing a relative error around *1%* and an excellent agreement on growth rates

- The introduction of the **gaps in the shell** has a small destabilizing effect. Induced current density distribution pattern in the shell is shown in *Fig. 2*, where gaps location and their effects on the current distribution are visible.

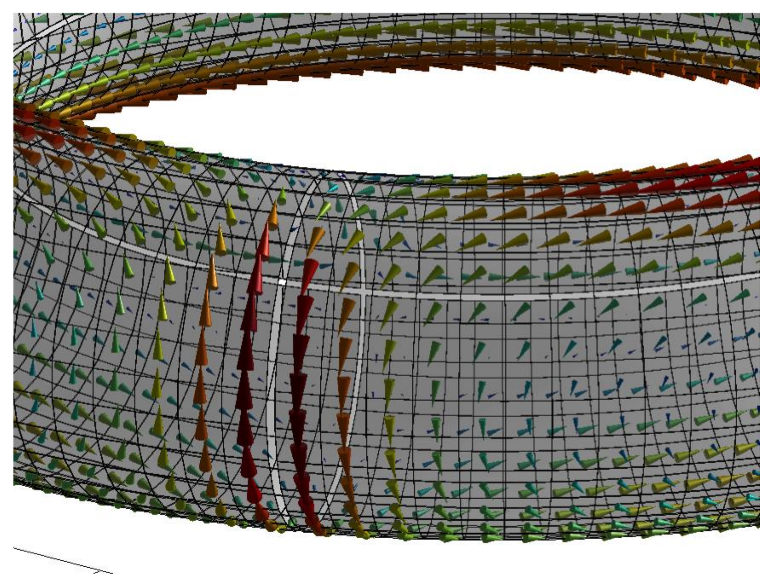


Fig. 2 Current density patterns on shell

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