



CREATE Tools for plasma magnetic modelling and control

Fast MPC or Magnetic Plasma Control

Kick-off Meeting

25 March 2015

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The ITER PCS Simulation Platform

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Main use cases

The **CREATE Tools** are set of Matlab/Simulink applications that have been developed since 2003

- ▶ to **allow non-experts to perform analysis** with 2D nonlinear magnetic equilibrium codes



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- ▶ to **allow non-experts to perform analysis** with 2D nonlinear magnetic equilibrium codes
 - ▶ to support the **design and validation of scenarios**
 - ▶ to support the **design and commissioning of plasma magnetic diagnostic**



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- ▶ to **automate the generation of linearized models** for plasma/circuits behavior

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- ▶ to **automate the generation of linearized models** for plasma/circuits behavior
- ▶ to **automate the design/validation/deployment** process of model-based plasma magnetic control systems
 - ▶ to support the **design plasma current, position and shape control algorithms**
 - ▶ to ease the **optimization of the control gains** between the experiments

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Main requirements

- ▶ The tools have been designed as a set of **machine independent** applications

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Main requirements

- ▶ The tools have been designed as a set of **machine independent** applications
 - ▶ **The requirement has been implemented for the modelling tools**

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Main requirements

- ▶ The tools have been designed as a set of **machine independent** applications
 - ▶ **The requirement has been implemented for the modelling tools**
 - ▶ **The requirement is NOT implemented for the control design tools**
 - ▶ The design and validation phases depend on the specific control algorithm
 - ▶ The deployment phase is intimately linked to the target real-time host
- ▶ The tools for control design and validation have been designed so that their outputs can be used to configure the plant system **without any further modification**

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- ▶ The tools for control design and validation have been designed so that their outputs can be used to configure the plant system **without any further modification** → *the JET experience*

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Modelling tools 1/2

- ▶ CREATE-L (*Albanese et al., Nucl. Fus. 1998*) & CREATE-NL (*Albanese et al, Fus. Eng. Des. 2003*)
 - ▶ 2D finite elements magnetic equilibrium codes



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Modelling tools 1/2

- ▶ CREATE-L (*Albanese et al., Nucl. Fus. 1998*) & CREATE-NL (*Albanese et al, Fus. Eng. Des. 2003*)
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 - ▶ can compute plasma equilibria in the presence of ferromagnetic materials and of eddy currents induced in the passive structures



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 - ▶ can produce linearized models



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 - ▶ CREATE-NL
 - ▶ computes both direct and inverse equilibrium
 - ▶ can be coupled with transport codes
 - ▶ allows to perform nonlinear simulations with Simulink (included in the first release of PCSSP)



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 - ▶ can be coupled with transport codes
 - ▶ allows to perform nonlinear simulations with Simulink (included in the first release of PCSSP)
 - ▶ **The availability of (at least) two independent modelling tools is essential during experimental activities for cross-validation of the predictive simulations** (e.g., inter-shot simulation aimed at optimizing the control gains)
 - ▶ Validated on an extensive set of devices (JET, TCV, MAST, EAST, FTU, RFX, ITER, ...)



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Modelling tools 2/2

- ▶ CREATE Egene (*De Tommasi et al., IEEE TPS 2007*)
 - ▶ exploits the linearized model to interactively compute the external currents required to modify the equilibrium (by changing the shape, I_p , β_p , and I_i)



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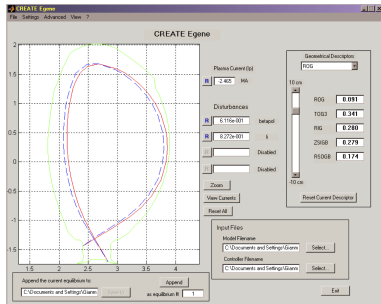
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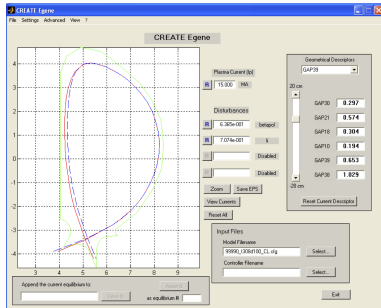
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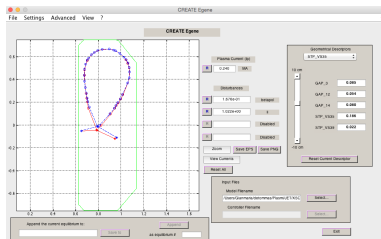
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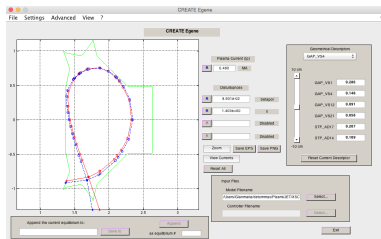
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EAST

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Control tools

- ▶ *XSC dependent*
 - ▶ XSC Generator (*De Tommasi et al., IEEE TPS 2007*)
 - ▶ automatically designs the eXtreme Shape Controller parameters taking the plasma linearized model and the *weights* set by the user as inputs

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 - ▶ CLA Generator (*De Tommasi et al., IEEE TPS 2012*)
 - ▶ automatically designs the Current Limit Avoidance parameters taking the plasma linearized model, the XSC gains and the *limits* set by the user as inputs

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 - ▶ CLA Generator (*De Tommasi et al., IEEE TPS 2012*)
 - ▶ automatically designs the Current Limit Avoidance parameters taking the plasma linearized model, the XSC gains and the *limits* set by the user as inputs
- ▶ *JET dependent*
 - ▶ XSC Simulator (*De Tommasi et al., IEEE TPS 2007*)
 - ▶ takes as inputs the linearized model and the XSC+CLA, and it allows the user to perform closed-loop simulations, and to compare the results with the JET experimental data

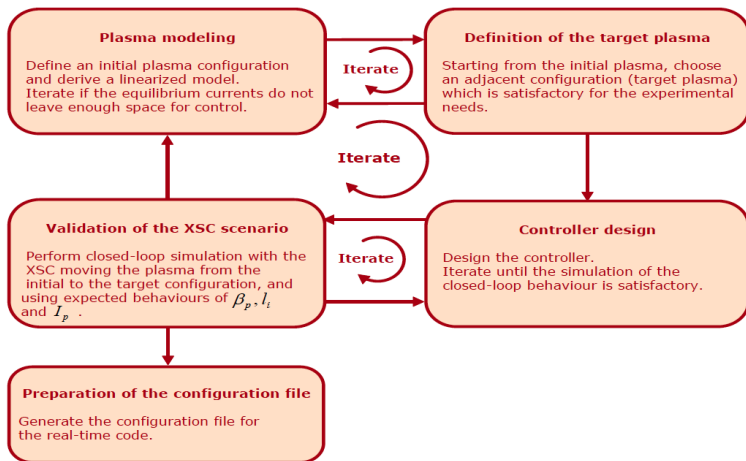
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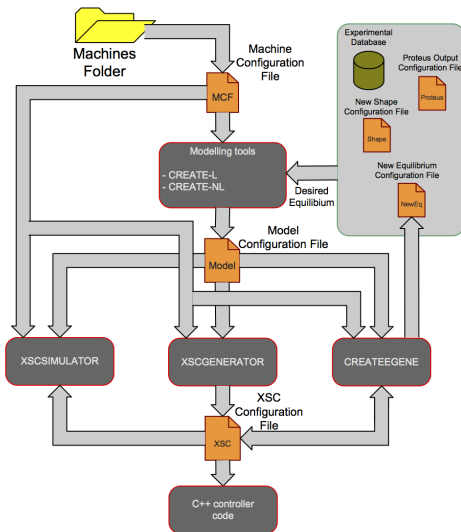
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The XSC Tool chain 1/2



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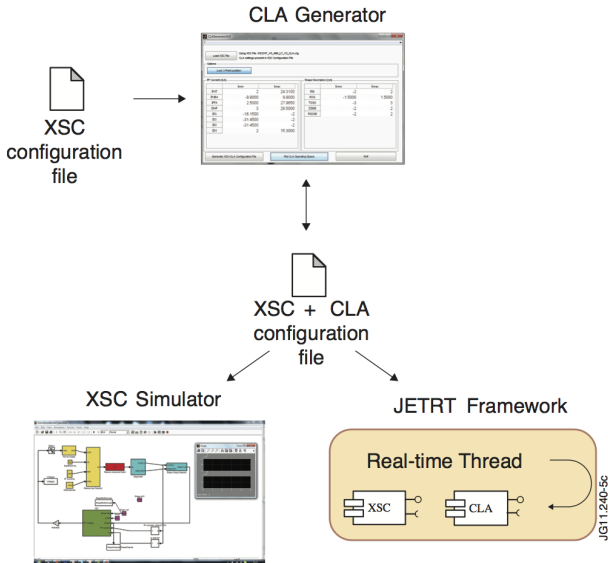
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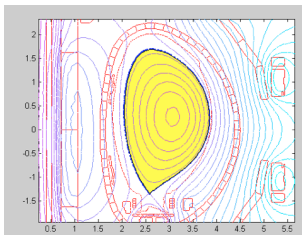
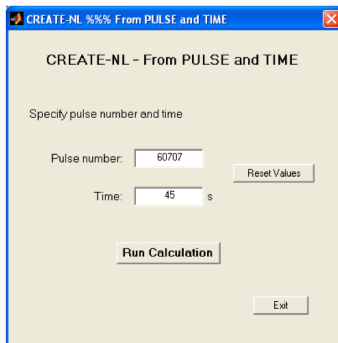
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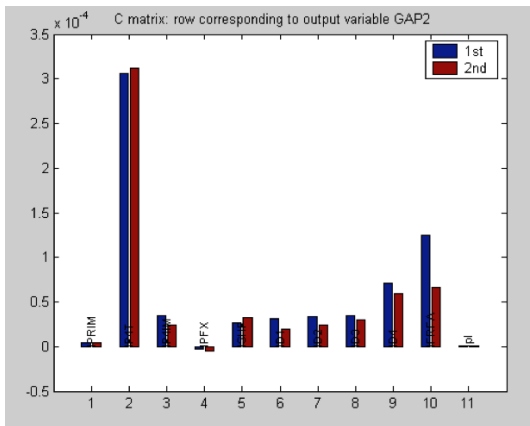
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Comparison between CREATE-L & CREATE-NL



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- ▶ A simulation environment (developed in Matlab/Simulink) known as the *Plasma Control System Simulation Platform* is currently under development (the team is led by GA, and includes IPP and CREATE)

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- ▶ A simulation environment (developed in Matlab/Simulink) known as the *Plasma Control System Simulation Platform* is currently under development (the team is led by GA, and includes IPP and CREATE)
- ▶ The PCSSP is specifically designed to support development of the ITER Plasma Control System (PCS)

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- ▶ A simulation environment (developed in Matlab/Simulink) known as the *Plasma Control System Simulation Platform* is currently under development (the team is led by GA, and includes IPP and CREATE)
- ▶ The PCSSP is specifically designed to support development of the ITER Plasma Control System (PCS)
- ▶ A first (not stable) version has been released in December 2013
- ▶ A new version is envisaged by the end of 2015

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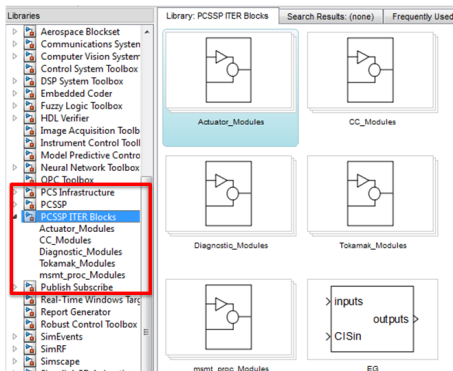
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- ▶ The current release of the PCSSP includes some Simulink libraries for
 - ▶ Generic modules (templates, signals conversion, *quality tags*, etc.)
 - ▶ ITER specific modules
 - ▶ (few) DIII-D specific modules
 - ▶ Publish & subscribe components (to ease the signal routing)

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- ▶ **CREATE contribution to the PCSSP**
 - ▶ Linear and **nonlinear (CREATE-NL)** model of plasma/circuit behaviour for the ITER tokamak
 - ▶ Model of ITER magnetic diagnostics
 - ▶ A set of magnetic controllers (plasma current and shape, vertical stabilization, PF current controller)

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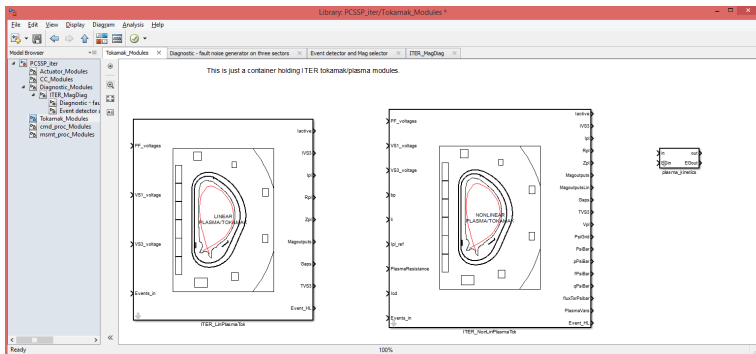
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The Nonlinear plasma model block within PCSSP

- ▶ In order to reduce the computational burden, the model is obtained by combining a nonlinear dynamic free boundary equilibrium solver with a linear model of the dynamics induced by eddy currents, including the $n = 0$ unstable mode modeling plasma vertical instability
- ▶ The combination of the two models allows simulation with both plasma shape and vertical stabilization control

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- ▶ The combination of the two models allows simulation with both plasma shape and vertical stabilization control
- ▶ The nonlinear free boundary equilibrium solver simulates the plasma shape and current evolution on the time scale of seconds. This dynamic is time-integrated with a suggested fixed time step of 100 ms (good trade-off suggested for ITER), and is implemented by wrapping into an S-function a light version of the CREATE-NL solver.

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The Nonlinear plasma model block within PCSSP

- ▶ The model is driven by voltages in the PF coil converters and a certain number plasma parameters depending on the simulation mode (e.g. poloidal beta, internal inductance, plasma resistance), and gives in output the evolution of the main plasma quantities, gaps, magnetic measurements and currents in circuits and coils

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- ▶ The following configuration must be specified
 - ▶ assigned I_p /self-consistent I_p
 - ▶ assigned profiles/external profiles (β_p, I_i)
 - ▶ spatial grid
 - ▶ specific equilibrium data
 - ▶ the linear model used for plasma vertical instability.

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- ▶ The possibility to compute linearized equilibria in real-time allows to
 - ▶ make real-time estimation of the plasma growth-rate
 - ▶ support disruption prediction algorithms

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- ▶ The possibility to compute linearized equilibria in real-time allows to
 - ▶ make real-time estimation of the plasma growth-rate
 - ▶ support disruption prediction algorithms
- ▶ **The CREATE tools have been developed for OFFLINE USE**
- ▶ Main engineering activities needed to generate linear equilibria in real time:
 - ▶ Simplification of the nonlinear equilibrium code
 - ▶ Optimization of the linear model computation
 - ▶ Deployment of the code on a high performance hardware (GPUs?,FPGA?)

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