EUROfusion
TECHNOLOGY TRANSFER PROGRAMME

NICE : Newton direct and Inverse Computation for Equilibrium

The code NICE (Newton direct and Inverse Computation for Equilibrium) is a Tokamak plasma equilibrium computation code licensed by the Univ. Cote Azur (UniCA) whose plasma simulation group has received funding from the Euratom research program since 2014. The strength of NICE is to gather in a single finite element framework different equilibrium computation modes. It makes intensive use of Newton method and Sequential Quadratic Programming method to solve non linear problems. Potential other applications include modeling space plasmas, industrial magnetohydrodynamics, improving medical imaging, geophycis, and control of free-boundary systems such as electromagnetic shaping of fluids or molten materials.
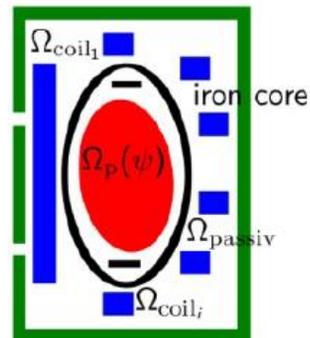
Description of the technology

The code NICE (Newton direct and Inverse Computation for Equilibrium) is a Tokamak plasma equilibrium computation code licensed by the Univ. Cote Azur (UniCA) and described in https://hal.archives-ouvertes.fr/hal-02955053. The code NICE enables to solve numerically several problems of plasma free-boundary equilibrium computations in a tokamak: plasma free-boundary only reconstruction and magnetic measurements interpolation, full free-boundary equilibrium reconstruction from magnetic measurements and possibly internal measurements (interferometry, classical linear approximation polarimetry or Stokes model polarimetry, Motional Stark Effect and pressure), direct and inverse, static and quasi-static free-boundary equilibrium computations.

The software NICE can be used for real-time plasma free-boundary reconstruction and magnetic measurements' interpolation. It can also be used inversely, to extrapolate the magnetic measurements and compute the plasma boundary itself. The same software can run a full freeboundary equilibrium reconstruction from magnetic measurements and possibly internal measurements (interferometry, classical linear approximation polarimetry or Stokes model polarimetry, Motional Stark Effect, and pressure). In this mode, the problem solved consists of the identification of the plasma current density, a non-linear source in the 2D Grad-Shafranov equation, which governs the axisymmetric equilibrium of plasma in a Tokamak. The software can also perform direct and inverse, static and quasi-static evolution free-boundary equilibrium computations.

Free-Boundary Equilibrium of Toroidal Plasma

Grad-Shafranov (GS) equation, the fundamental equation for tokamaks:

$$-\nabla \cdot \left(\frac{1}{\mu(\psi)_T} \nabla \psi \right) = \begin{cases} rp'(\psi) + \frac{1}{\mu_0 r} ff'(\psi) & \text{in } \Omega_\mathrm{p}(\psi), \\ I_i/|\Omega_{\mathrm{coil}_i}| & \text{in } \Omega_{\mathrm{coil}_i}, \\ j^{ind} & \text{in } \Omega_{\mathrm{passive}}, \\ 0 & \text{elsewhere}, \end{cases}$$

poloidal flux ψ, the toroidal comp. of $r\mathbf{A}$, $\mathbf{B} = \operatorname{curl} \mathbf{A}$
pressure p and f toroidal comp. of $r\mathbf{B}$.

Figure 1: The equation and the geometry for a simulation of a free-boundary toroidal plasma equilibrium in the poloidal cross-section. For a description of the GS equation notation, we refer to https://hal.science/hal-03423469.

EUROfusion
TECHNOLOGY TRANSFER PROGRAMME

NICE : Newton direct and Inverse Computation for Equilibrium

The code NICE (Newton direct and Inverse Computation for Equilibrium) is a Tokamak plasma equilibrium computation code licensed by the Univ. Cote Azur (UniCA) whose plasma simulation group has received funding from the Euratom research program since 2014. The strength of NICE is to gather in a single finite element framework different equilibrium computation modes. It makes intensive use of Newton method and Sequential Quadratic Programming method to solve non linear problems. Potential other applications include modeling space plasmas, industrial magnetohydrodynamics, improving medical imaging, geophycis, and control of free-boundary systems such as electromagnetic shaping of fluids or molten materials.

Innovation and advantages of the offer

NICE unifies and upgrades 3 former codes VacTH, EQUINOX and CEDRES++ . The strength of NICE is to gather in a single finite element framework different equilibrium computation modes. It makes intensive use of Newton method and Sequential Quadratic Programming method to solve non linear problems. It uses a modular approach that builds around a standardized data representation that can describe both experimental and simulation data. The code NICE is also coupled to a magnetic feedback controller making it possible to simulate a prescribed plasma scenario, see https://hal.science/hal-04589897

Non-fusion Applications

The NICE code, designed for tokamak plasma equilibrium, can be applied beyond fusion wherever direct or inverse free-boundary problems arise. Potential uses include modeling space plasmas (solar or planetary magnetic equilibria), optimizing industrial magnetohydrodynamics (liquid metal flows, crystal growth), improving medical imaging (MRI, MEG), reconstructing geophysical or structural fields from surface data, and controlling free-boundary systems such as electromagnetic shaping of fluids or molten materials. For example, the research team has received in 2025 a funding from FUTTA (EUROfusion WP Technology Transfer) for a project further using the NICE Code to optimize the design of non pyrotechnic hold-on and release mechanism for space application.

EUROfusion Heritage

This code is used to simulate several problems related with plasma freeboundary equilibrium in a Tokamak. NICE is used routinely for WEST tokamak operation and the STEP team (UKAEA) signed a use contract license in 2023. The simulation work is carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Program (Grant Agreement No 101052200 – EUROfusion). The plasma simulation group in UniCA has received funding from the Euratom research program since 2014. As a latest achievement (Spring 2024), the software NICE will be used to design a plasma discharge simulator (PDS) in the `PDS architecture and Free-Boundary-Equilibrium integration', a contract of the consortium CEA – UniCA - Ignition Computing with the ITER organization.

Visit our website to learn how fusion can help your business
www.tech-transfer.eurofusion.eu