TECHNOLOGY BRIEF

NEXT STEP FUSION

NSFsim: Integrated Modeling for Tokamak Design and Operation

An integrated tokamak simulation platform built around a 2D Grad–Shafranov equilibrium solver coupled to a 1D radial kinetic model — linking equilibrium, reconstruction, plasma evolution, heating and disruptions with external codes in one self-consistent environment.

THE PLATFORM

The Next Step Fusion Simulator (NSFsim) links built-in magnetic equilibrium, reconstruction, plasma evolution, heating (and current drive), and disruption modeling with external codes in a single self-consistent environment, enabling scenario design and control-oriented workflows [1]. The platform is extensible by design: transport, heating, impurity, scrape-off-layer (SOL), and MHD stability codes plug into the Fortran core through a Python API toolkit, while a built-in plant model connects the physics to plasma control systems and reinforcement-learning training. Everything is accessible through the FusionTwin.io web platform and a public API (Python, C++, MATLAB/Simulink).

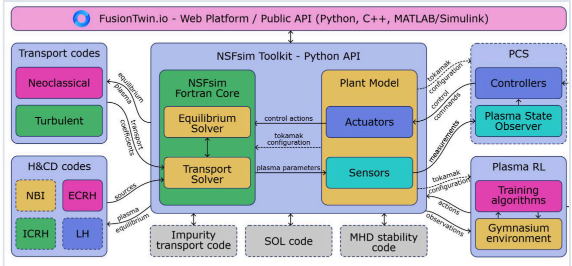

Fig. 1. NSFsim architecture: the Fortran core (equilibrium and transport solvers) and plant model sit under a Python API toolkit, coupled to transport, heating, impurity, SOL and MHD stability codes, the plasma control system, and RL training environments [1].

FORWARD AND INVERSE SOLVING

In its core forward mode, NSFsim takes coil currents, plasma-current evolution and kinetic profiles, and computes the plasma equilibrium, poloidal-flux evolution, and radial temperature and density profiles, with shared-memory coupling to external tools such as TRAVIS [2] and ASCOT5 [3]. The inverse solver works the other way: it determines the coil currents needed to achieve a prescribed plasma state directly from physical inputs — current, density, and ion/electron temperature profiles. The scenario builder extends the inverse problem to a time-dependent discharge, calculating how coil currents and voltages should evolve so the plasma follows a prescribed trajectory — ramp-up, current evolution, and pulse design studies validated against experiment (Fig. 2).

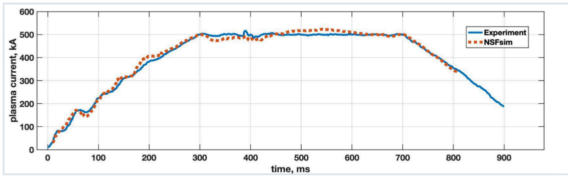

Fig. 2. Experimental and NSFsim plasma current evolution for a selected discharge using the internal 1D transport solver [1].

STARTING BEFORE THE PLASMA EXISTS

The latest addition is the first version of the breakdown and burn-through module. NSFsim now models the formation of the electron avalanche, the 0-D evolution of the plasma kinetics throughout burn-through, and the evolution of the magnetic-coil currents and voltages that provide a field null at breakdown and maintain the required magnetic configuration through early plasma initiation. Discharge scenarios can now be simulated from the very beginning — before the plasma exists.

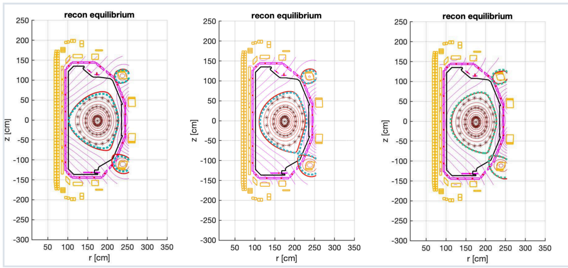

Fig. 3. EdFIT reconstruction: NSFsim psi contours (magenta/red) against the EFIT boundary (cyan dotted line) for a negative-triangularity DIII-D discharge [1].

DISRUPTIONS AND RECONSTRUCTION

The disruption module supports modeling of major disruptions and vertical displacement events, resolving toroidal vessel currents throughout the thermal and current quench. EdFIT, the equilibrium reconstruction module, recovers the magnetic plasma state from diagnostic signals — plasma current, coil currents, flux loops, and magnetic probes — with fixed- and floating-filament reconstruction and diagnostic weighting for unreliable sensors (Fig. 3).

UNDER DEVELOPMENT

3D currents in conducting structures — computing 3D current distributions in conducting structures and their influence on the subsequent equilibrium evolution.

Aneutronic fusion — p-^{11}B reaction modeling for aneutronic-fusion studies, expanding NSFsim toward alternative fusion reactions.

Stellarators — a dedicated module extending NSFsim calculations to stellarator configurations.

Scrape-off layer — a hierarchy of SOL models for pulse design, from the current 0D model [4] toward more complete reactor-relevant simulations.

ONE PLATFORM, THE WHOLE LIFECYCLE

NSFsim is the core of Next Step Fusion's **integrated modeling** offering — one toolchain supporting a fusion device from feasibility studies and magnetic system design through disruption and load assessments to plasma control developed on a **digital replica** of your device.

The simulator is extensively verified and validated against experimental data from multiple tokamaks.

REFERENCES

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2. N. B. Marushchenko, Y. Turkin, H. Maassberg, "Ray-tracing code TRAVIS for ECR heating, EC current drive and ECE diagnostic," Comput. Phys. Commun. 185, 165–176 (2014).
3. J. Varje et al., "High-performance orbit-following code ASCOT5 for Monte Carlo simulations in fusion plasmas," arXiv:1908.02482 (2019).
4. X. Zhang et al., "Reduced physics model of the tokamak Scrape-Off-Layer for pulse design," Nucl. Mater. Energy 34, 101354 (2023).

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Designing or operating a magnetic confinement device? The earlier we engage, the better the outcome.