Development of a Predictive Simulation Capability for Three-Dimensional Configurations

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Panel Reports and DOE Statements

The major review panels and DOE have presented a broad vision for a fusion simulation program which is at odds with the exclusive focus of SCIDAC and proto-FSP projects on tokamaks.

Report of FESAC "Priorities, Gaps and Opportunities" panel (Greenwald Panel)

Gap "G-6. Sufficient understanding of alternative magnetic configurations that have the ability to operate in steady-state without off-normal plasma events."

Finding: "The principle strategy to mitigate risk is to implement a sufficiently broad program so that alternative approaches or technologies are available at each step."

A major issue: **"**3. Validated Theory and Predictive Modeling: Through developments in theory and modeling and careful comparison with experiments, develop a set of computational models that are capable of predicting all important plasma behavior in the regimes and geometries relevant for practical fusion energy."

Report of FESAC Toroidal Alternates Panel, in its "Findings" lists "predictive capability" as one of the four highest priority ("tier 1") issues for stellarators: "The reduced experimental database for stellarators … places a greater burden on validated predictive models in the design process for a burning plasma experiment."

Request for proposals released by DOE for the Fusion Simulation Program (FSP):
"The goal of the FSP is to develop a world-leading, experimentally validated predictive simulation capability for fusion plasmas in the regimes and geometries relevant for practical fusion energy." The document goes on to say that while "…the FSP will be an important asset for maximizing the return of our investment in ITER… the scope of the FSP is much wider as it is being envisioned as a tool that embodies our predictive understanding of magnetically confined plasmas in regimes and geometries relevant for practical fusion energy…"

Status

SCIDAC and proto-FSP projects are focused exclusively on tokamaks. A stellarator effort could leverage off of this activity, developing a broadened simulation capability with a relatively modest amount of additional effort. Many of the major codes for the numerical simulation of tokamaks are inherently three-dimensional. Time-dependent MHD codes, for example, deal with the 3D time-evolution of tokamak plasmas. Major gyrokinetic codes for tokamaks are also three-dimensional. The capability of these codes to handle stellarators is limited primarily by their inability to couple to 3D equilibrium codes. The GS2 flux-tube gyrokinetic code, for example, was modified to handle stellarators with good flux surfaces (VMEC equilibria) by a graduate student working part time on this task as a second-year theory project while also taking courses and studying for a general exam. While this is an extreme example, it is generally the case that the effort that would be required to couple these codes to 3D equilibrium codes would be quite small relative to the effort expended in developing the codes. Such a coupling effort would also fit naturally into the direction in which fusion simulation research is moving, of developing methods to couple codes to provide an integrated simulation capability.

Potential Benefits to Tokamak Research

The tokamak community itself would directly benefit from a capability to handle 3D equilibria. Tokamak equilibria, while nominally axisymmetric, are in practice often nonaxisymmetric. There are imposed nonaxisymmetric fields: field errors; fields from field error correction coils which, while canceling the resonant field at its rational surface, also introduce a broad spectrum of additional nonaxisymmetric fields; fields for stabilizing ELMs. Nonaxisymmetric fields may also be present due to saturated instabilities such as neoclassical tearing modes. Additionally, stellarator experiments provide opportunities not available in tokamaks for validating key pieces of the numerical physics models, such as those related to neoclassical toroidal viscosity (NTV), which is now recognized to play an important role in tokamaks with field errors or resonant magnetic perturbations (RMPs). Finally, it may prove desirable to introduce some nonaxisymmetric fields in tokamaks beyond those used to stabilize ELMs. For example, there is a study evaluating the possible use of relatively simple sets of nonaxisymmetric saddle coils to stabilize vertical modes in tokamaks. Stellarator computational tools will be required to evaluate such proposals.

Requirements

Development, verification and validation of codes to simulate stellarators. Coupling the codes to provide an integrated, predictive simulation capability for stellarators.

Thrust

Begin coupling major 3D tokamak codes to 3D equilibrium codes. The development of an integrated, predictive simulation capability for 3D configurations should be an integral part of the fusion simulation program in the U.S..