

Computational Needs for Reversed-Field Pinch and Spheromak Development*

Carl Sovinec

University of Wisconsin-Madison

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*A bibliography is available in the whitepaper (Theme 5, #13).

Executive Summary

- Relaxation-related topics will need continuing support from nonlinear macroscopic computation (with 2-fluid and kinetics).
 - Achieving large dimensionless parameters (S , H) with cascading fluctuations remains challenging due to increasing ranges of scales.
 - Computational efficiency improvement and dedicated capacity (parallel and reliable) computing resources are needed.
- Hard vs. soft β -limits, resistive wall/feedback, and energetic particle effects can be investigated with enhanced macro computation.
- Existing microscopic turbulence computation can be used to investigate magnetically quiescent transport; however:
 - Synergistic electrostatic turbulence and 3D magnetic topology evolution may be more realistic.
 - Integration is expected to be a major Fusion Simulation Project (FSP) effort, which will need coordination and direction to be sufficiently general.
- RF modeling will be useful for current sustainment and profile control.
 - Integration with macro relaxation effects is important (FSP) and modeling needs to be suitable for low-field conditions.
- Coupling of core and edge physics is important for these devices.
 - Integration of macro and edge plasma models will be useful (FSP).

Review of Computational Contributions to TAP Issues

- Current sustainment with high confinement
 - Computation has provided a reasonably detailed description of relaxation processes, according to resistive MHD, in both configurations
→future: larger S and H numbers; two-fluid.
 - Macroscopic computation has been used to investigate transients and AC current drive schemes→larger S ; two-fluid; optimization studies.
- Transport and confinement scaling
 - $0\text{-}\beta$ resistive MHD has provided scaling of fluctuations and intermittency
→larger S ; two-fluid.
 - Synergy with transport has been described with collisional closures→two-fluid; kinetic closure.
 - Gyrokinetics study for magnetically quiescent conditions is just starting→nonlinear; global; combine with macro.
- Plasma β -limits (low- q ; no good curvature)
 - Linear computations have been used for interchange and pressure-driven tearing→drift and energetic particle effects.
 - Pressure-driven modes are included in nonlinear macro computations with energy evolution→drift and kinetics.
- Resistive wall modes
 - Early nonlinear studies modeled RFPs.
 - With feedback modeling, simulations can help optimization.

Computational Requirements

- Macroscopic (MHD-like) computation:
 - Typical reduced models are not suitable.
 - Anisotropy with magnetic fluctuations and evolving topology requires accuracy without mesh alignment.
 - Computational efficiency **and reliable hardware for communication-intensive applications are needed** for conditions of cascading fluctuations.
 - Spheromaks need simply connected domains.
 - Simulation of some experiments will require fully 3D meshing.
 - Kinetic extensions for parallel free-streaming effects are important for quantitative transport.
 - Minority species kinetics are needed for energetic-particle effects.
 - General kinetic closure can provide information on thermalization.
 - Validation requires direct comparison with magnetic-fluctuation and profile measurements. **Experimental data over a range of conditions (not just best performance) are needed.**

Computational Requirements (continued)

- Microscopic turbulence computation:
 - With qualifications on k_{\parallel}/k_{\perp} assumptions, standard flux-tube computations can be applied to magnetically quiescent, core plasma conditions.
 - Toroidal magnetic flux is not suitable as an independent variable in global computations.
 - Validation may not be feasible if residual magnetic fluctuations remain important experimentally.
 - Integration of microscopic turbulence with macroscopic dynamics requires both analytical and computational development.
 - It will likely be one of the most challenging aspects of FSP; kinetics in evolving 3D fields requires much more than 1D transport as an intermediary between loosely coupled simulations.
 - Direction to produce a sufficiently general simulator (for RFPs, spheromaks, ...) is needed.

Computational Requirements (continued)

- RF computation:
 - Must be suitable for overdense (wrt electron cyclotron) conditions.
 - Macroscopic fluctuations need to be considered for accurate predictions of propagation.
 - FSP integration efforts need to be sufficiently general.
- Edge modeling:
 - RFPs and spheromaks are at least as sensitive to edge plasma conditions as tokamaks; 2D and 3D modeling is needed.
 - Conditions in the outer part of the core/inner part of edge have been critical.
 - FSP integration of core and edge plasma modeling needs to be sufficiently general.
 - Simulation studies can help design RFP divertors that avoid coupling to core tearing.

Concluding Remarks

- Similarities in RFP and spheromak physics carries through to computational needs.
- Simulation flexibility will serve cross-cutting thrusts.
- Two-way coordination with FSP will be critical.
- Hardware investments need to consider high-performance capacity requirements.
 - ‘Earth Simulatoritis’ at national computer centers needs mitigation.
- There is a question of whether fusion plasma computation should be a thrust of its own.
 - Author’s opinion: This is appropriate at the FSP level.
 - It would not be good if it extracts computation from other efforts, however.