Proposed New Initiative in Disruption Modeling

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Background:

The International Tokamak Physics Activity (ITPA) on MHD, Disruptions, and Plasma Control has met twice a year for over 12 years to bring focus to the disruption issue and to aid the ITER Organization (IO) in making design decisions related to disruptions. Many results of disruption related experimental campaigns have been reported, and many inter-machine studies have been carried out and working groups formed. The overwhelming majority of results presented at ITPA meetings are by experimental teams, but there are also some important modeling results that have been presented.

The US delegation has played a lead role in the modeling by providing and modifying the 2D TSC code and the 3D NIMROD and M3D codes. The modeling efforts with these codes have been partially funded over the last 12 years by the CEMM SciDAC program, and also more recently by direct contracts with the IO . Both V. Izzo and S. Jardin of CEMM are members of the ITPA and normally participate in the semi-annual meetings, as do others in the modeling community. However, the effort now devoted to disruption modelling in the US is far less than what is required in order to fully support the experimental program and reliably extrapolate results from today's experiments to ITER.

Proposed New Initiative

We feel that the Extended-MHD codes such as NIMROD and M3D-C1 should continue to form the backbone of the disruption modeling effort. They solve the 3D magneto- fluid conservation equations and are capable of describing ideal-MHD timescale behavior as required to model the thermal quench. Efficient implicit algorithms also give these codes the capability to access long transport time scales as required to model the current quench, and more challenging, the slow evolution of locked modes. They have the capability of defining the full time-evolving magnetic geometry from the hot core, through the separatrix, out to the divertor/walls and coils.

These codes require improved source and sink terms and improved kinetic closures in order to model many effects that potentially play a role in disruptions. Improved impurity modeling including impurity radiation is essential for modeling density limit disruptions and the effectiveness of mitigation strategies involving impurity injection. Improved kinetic closures are required for modeling Neoclassical Tearing Modes, full ELM cycles, and the evolution of locked and resistive wall modes. Disruption induced runaway electron models need to be developed to model existing experimental results, the interaction of runaways with MHD, and the extrapolation of these to ITER. Improved models of massive gas injection and shattered pellet injection need to be developed and implemented to help design fail-safe mitigation strategies.

The codes now have the capability of including different regions so as to include plasma, conducting structures, and "vacuum". Boundary conditions between the different regions need to be compared with experimental results and other effects such as sheath voltage drops need to be included as required. The heat loads on the divertor plates from disruptions and from ELMs need to be compared with experimental results as available.

Applied Math and Computer Science Involvement.

As the resolution requirements increase, the condition number of the implicit matrices used by the codes increases, necessitating the use of smaller time-steps and/or more iterations per time-step. There is a need for improved preconditioners to help counter this tendency, and hence improve the weak parallel scaling of the codes as the size of the matrices increase. Forming the preconditioners themselves are expensive and their reuse should be looked into.

For some applications, the XMHD codes need to be coupled to other neutrals, RF, and/or kinetic codes and modern techniques for coupling massive parallel codes need to be implemented.
The codes also need to be restructured to make effective use of the next generation of computers which will likely use either GPUs or processing units similar to the Knights Landing Intel Xeon Phi processor. In order to get the speedup these units promise, extensive rewriting may be necessary in order to efficiently implement 3 levels of parallelism

Prioritized list of applications and their dependencies

	Application	**Validation Experiments**	**Comments**	**Required coding**	**Desired coding**
1	Sawtooth and seed island gen.	DIIID, NSTX, AUG	Compare with 2D ECI; Ph	A	C,D,F
2	Thermal quench	NSTX, DIIID, AUG	Soft vs. hard β limit island overlap	G	C,D,F
3	NTM excitation and growth	AUG, NSTX, DIIID	PhD. Thesis & MPPC postdoc	A, E	C,D,F
4	ELM studies	DIIID, NSTX, AUG	Includes RMP & CPES	E	C,D,F
5	Density limit modeling	CMOD?	Gates, Delgado TSC benchmark	G	C,D,F
6	RWM Studies	NSTX, DIIID	Compare with MARS & CU code	B, H	C,D,F
7	Runaway e-confinement	DIIID	Compare fluid and particle models for runaways	J	C,D,F
8	3D wall forces	NSTX, DIIID, AUG	With ports	B	C,D,F
9	Disruption mitigation	DIIID, NSTX	Compare with TSC model	B,I,G,J	C,D,F

New coding and capabilities planned for NIMROD and M3D-C^1

A. Implement island detection algorithm in M3D-C^1
B. Implement and verify resistive wall for nonlinear mode in M3D-C^1 and NIMROD
C. Implement GPUs and/or optimizations to do integrations in M3D-C^1
D. Improve preconditioners for 2F high resolution and large $\kappa_{||}$ in M3D-C^1
E. Implement and verify full neoclassical model in NIMROD and M3D-C^1
F. Explore preconditioner reuse in M3D-C^1
G. Incorporate multiple ion species and radiation in M3D-C^1
H. Implement kinetic damping terms in NIMROD and M3D-C^1
I. Implement neutrals, pellet and MGI models in NIMROD and M3D-C^1
J. Implement self-consistent runaway electron models in NIMROD and M3DC^1