

MHD aspects of NTSX-U & Theory cooperation

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Objectives	<p>Comprehensive consideration of linear and quasi-linear MHD stability. It includes:</p> <ul style="list-style-type: none"> (a) creation of a quasi-linear tokamak equilibrium code (PEQC) for 3-D perturbations; (b) extension of stability analysis to the plasma edge, including separatrix; (b) use PEQC for simulation of external perturbations at the plasma edge in NSTX-U; (c) extension of PEQC to self-consistent simulations of the Scrape off Layer currents. (d) addressing the needs in stability analysis of the LiWF regime on NSTX-U with finite current density and pressure gradient at the separatrix. (e) performing 3-D (quasi-linear) simulations of the wall touching kink mode (WTKM)
Motivation	<ul style="list-style-type: none"> (a) ideal MHD is insufficient for understanding edge stability of NSTX-U plasma; (b) the existing IPEC is not an equilibrium code (extension of the ideal MHD DCON); (c) the use of vacuum field perturbations neglects the plasma response; (d) attempt to reveal the physics mechanism of the thermal quench.
Scope of work 1 ZFTE*	<ul style="list-style-type: none"> (a) implementation of ψ-form of the energy principle (advantages: driving effects are explicit, applicable for both ideal and non-ideal plasma, simple interface with equilibrium, no convergence problem); (b) work is in progress on a reduced MHD version of PEQC under IO contract on RE; (c) development of full version of PEQC.
Validation:	New, ψ- form of energy principle resulted in 2005 in predictions of stabilization of ELM in Li assisted regimes
Application:	<ul style="list-style-type: none"> (a) global stability, beta limits and edge stability in NSTX-U in the presence of RMP and active plasma control; (b) simulations of RE production and losses by interfacing PEQC with IO set of codes on plasma jet and energetic particle modeling.
Deliverables:	<ul style="list-style-type: none"> (a) Guidance and assistance in developing the lithium wall fusion regimes; (b) provide practical tools for simulation of thermal quench, WTKM and RE losses; (c) create a science based bridge for application of NSTX stability results to ITER.

* **ZFTE** stands for one year Zakharov's full time equivalent.

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Objectives	<p>Create understanding of VDE and interpretation of plasma-to-wall currents in NSTX-U</p> <p>(a) develop a realistic numerical model of vertical instability;</p> <p>(b) create a practical model for 3-D conducting in-vessel elements of NSTX-U;</p> <p>(c) provide a guidance for designing special tiles for measuring the Hiro currents;</p> <p>(d) clarify the role of Hiro, Evans, eddy, and “halo” currents in VDE.</p>
Motivation	<p>(a) Theory has undermined the community shared paradigm of “halo” currents;</p> <p>(b) “halos” have been dismissed as asymmetric wall currents in all JET VDEs;</p> <p>(c) VDE is the cleanest case for developing a basic understanding of disruptions;</p>
Scope of work 1 ZFTE*	<p>(a) modify ESC code for simulation of a $n=0$ linear vertical mode in NSTX-U;</p> <p>(b) provide a guidance for installation in NSTX-U Hiro currents sensors (as in EAST);</p> <p>(c) create a 3-D model of the conducting in-vessel components of NSTX-U using Cbshl code;</p> <p>(d) modify ESC for simulations of VDE, including plasma-wall current sharing.</p>
Validation:	<p>(a) calibrate the 3-D wall model against calibration shots in LTX and NSTX-U;</p> <p>(b) reproduce both magnetic signals and tile/Hiro currents in VDE in NSTX-U;</p>
Application:	<p>(a) amplitudes and localization of forces for design purposes;</p> <p>(b) appropriate interpretation of measurements for the plasma stability control;</p> <p>(c) assessment of VDE effects on the liquid lithium layers in NSTX-U;</p>
Deliverables:	<p>(a) realistic physics & numerical model of VDE in tokamaks;</p> <p>(b) new diagnostics for the Hiro currents in the wall;</p> <p>(c) simulation tools for assessing the effect of VDE on ITER beryllium tiles.</p>

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Objectives	<p><i>Develop fast numerical tools for 3-D analysis in NSTX-U and 3-D equilibria in general</i></p> <p><i>(a) implement Hamada principle (unused since 1960) for the case of good flux surfaces.</i></p> <p><i>(b) implement the Reference Magnetic Coordinates (RMC) for ergodic fields;</i></p> <p><i>(c) create a fast 3-D equilibrium code LEE based linearized equilibrium equations.</i></p>
Motivation	<p><i>(a) needs of plasma edge physics (RMP, SoL) and disruptions simulations;</i></p> <p><i>(a) widely used VMEQ does not treat properly 3-D resonance surfaces;</i></p> <p><i>(b) PIES with tracing field lines is slow and impractical;</i></p> <p><i>(c) two innovative elements in 3-D theory: LEE and RMC promise high performance.</i></p>
Scope of work 2 ZFTE*	<p><i>(a) develop a 2-D version of LEE for fast calculations of tokamak equilibria;</i></p> <p><i>(b) extend the 2-D version on tokamak configurations with perturbed magnetic field;</i></p> <p><i>(c) develop a 3-D version for configurations with good flux surfaces;</i></p> <p><i>(d) implement the RMC into LEE for configurations with ergodic magnetic fields.</i></p>
Validation:	<p><i>(a) benchmark against 2-D ESC;</i></p> <p><i>(b) use of LSODE with a prescribed accuracy in solution.</i></p>
Application:	<p><i>(a) RMP-ELM analysis of NSTX-U plasma;</i></p> <p><i>(b) 3-D effects from the in-vessel conducting components in NSTX-U;</i></p> <p><i>(c) assessment of VDE effects on the liquid lithium layers in NSTX-U;</i></p>
Deliverables:	<p><i>(a) science based loop hole free 3-D equilibrium solver;</i></p> <p><i>(b) a basic component of the disruption simulation code.</i></p>

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Objectives	<p>Create a DSC and MHD simulations basis consistent with the basic properties of the tokamak plasma: high anisotropy, and unrestricted motion to the wall.</p> <p>(a) implements RMC based grids, consistent with the high plasma anisotropy; (b) create the free boundary plasma with no wide spread “salt water” limitations; (c) interface the core MHD with the boundary physics and realistic wall geometry; (d) following Kadomtsev-Pogutse get rid of magneto-sonic limitation on the time step</p>
Motivation	<p>Implementation of an appropriate plasma physics into MHD simulations is urgent:</p> <p>(a) 3-D MHD codes use hydrodynamics, rather than plasma physics, schemes; (b) NIMROD and M3D are irrelevant to tokamak disruption physics because of $V_n=0$; (c) Both failed of addressing critical ITER needs in assessing disruption forces ; (d) Wall touching kink mode (WTKM) needs to be simulated;</p>
Scope of work 2 ZFTE*	<p>(a) implementation of two versions of adaptive grids: (1) clouds of points, (2) RMC; (b) interfacing core plasma calculations with 3-D model of the in-vessel structures of tokamaks; (c) validation of model against the LTX (in future NSTX-U) calibration shot data; (d) initiation of regular simulations of VDEs mixed with kinks in NSTX-U.</p>
Validation:	<p>(a) reproducing in simulation the JET VDEs measurements;</p>
Application:	<p>(a) ITER urgent needs in resolving disruption problem; (b) identification of similarity in disruptions physics between NSTX-U and tokamaks; (c) assessment of the effect of disruption on in-vessel components in NSTX-U</p>
Deliverables:	<p>(a) a plasma physics based MHD numerical code for disruption simulations.; (b) 2-D version of DSC was created in 2011 and is capable of simulation of WTKM.</p>

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Objectives	<p><i>Creation of a real time mechanism for prediction of discharge parameters:</i></p> <p>(a) <i>enhance the existing equilibrium reconstruction technique with variance analysis;</i></p> <p>(b) <i>create a fast and flexible for real time modifications a transport simulation code;</i></p> <p>(c) <i>implement the transport code profiles as “signals” in reconstruction;</i></p> <p>(d) <i>arrange ahead-of-time (e.g., in the next $0.5\tau_E$) predictions of the discharge.</i></p>
Motivation	<p><i>ITER: no more empirical approach for specifying disruption-free operations space.</i></p> <p>(a) <i>rigorous theory was created for assessing validity of equilibrium reconstruction.</i></p> <p>(b) <i>ESC was complemented with new abilities;</i></p> <p>(c) <i>ASTRA transport code is interfaced with ESC; in 2007 demonstrated RTF abilities;</i></p>
Scope of work 0.5 ZFTE*	<p>(a) <i>implementation of variances technique into equilibrium reconstruction;</i></p> <p>(b) <i>development an interface of equilibria with a separatrix and transport codes;</i></p> <p>(c) <i>utilization of the transport calculated profiles as signals in reconstruction;</i></p> <p>(d) <i>arrange both real time adjustment and predictive mode for transport simulations.</i></p> <p>(e) <i>real time interface with NSTX-U diagnostics;</i></p>
Validation:	<p>(a) <i>post discharge reproduction of the experimental data on NSTX-U;</i></p> <p>(b) <i>field test of REFIT reconstruction on NSTX-U enhanced by RTF abilities;</i></p>
Application:	<p>(a) <i>plasma control for NSTX-U, DIII-D and for JET, EAST, KSTAR, ITER;</i></p> <p>(b) <i>validation of the transport and stability models for tokamak plasma;</i></p>
Deliverables:	<p>(a) <i>ASTRA-ESC code system s a prototype of RTF;</i></p> <p>(b) <i>enhanced plasma control system for NSTX-U;</i></p>

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Objectives	<p>Create an understanding the flux tube phenomena at the plasma edge in NSTX-U.</p> <p>(a) create the basic theory mechanism for consideration of flux tube configurations; (b) implement the theory into 3-D flux tube numerical code; (c) interface the code with NSTX-U measurements for developing interpretation;</p>
Motivation	<p><i>Simplistic understanding of the plasma edge as a set of flux surfaces was shaken by RMP experiments on DIII-D and SoL measurements.</i></p> <p>(a) there is no basic justification of the “ideal” MHD plasma model for edge stability; (b) DIII-D proved that field lines from the pedestal region are linked with the tiles; (c) the role of SoL currents is not yet revealed; (d) <i>edge 3-D MHD remains essentially an untouched area.</i></p>
Scope of work 1 ZFTE*	<p>(a) extend the space curve equilibria theory to flux tube at the tokamak edge; (b) create a numerical code for extraction of edge flux tube parameters from NSTX-U configurations; development an interface of equilibria with a separatrix and transport codes; (c) create a 3-D code (in the reduced MHD approximation) for flux tube equilibria; (d) arrange processing the NSTX-U data on flux tube events;</p>
Validation:	<p>(a) reproduction of the experimental measurements on NSTX-U;</p>
Application:	<p>(a) plasma edge stability control; (b) assessment of the edge stability in the LiWF regime.</p>
Deliverables:	<p>(a) the theory of the flux tube equilibria for the plasma edge and astrophysics phenomena; (b) the flux tube equilibrium code interfaced with NSTX-U data base.</p>