Final Scientific/Technical Report
DE-SC0018030 Project – 30492
General Atomics

Project Recipient: Todd Evans

Title: Modeling plasma response to non-axisymmetric magnetic field perturbations in tokamak boundaries

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Abstract

The primary goal of this project is to provide physics insight into models that elucidate the mechanisms responsible for controlling the performance of H-mode plasmas and edge localized mode (ELM) stability when subjected to intrinsic and applied non-axisymmetric magnetic perturbations. The overall goal is to facilitate the development of physics-based criteria for the design of magnetic coils to be used for ELM suppression and H-mode pedestal control in future burning plasma devices such as ITER. The specific objectives of the project are organized into 3 tasks: (1) extend the capabilities of existing linear and nonlinear resistive MHD codes, for example M3D and M3D-C1, in order to study multi-mode non-axisymmetric magnetic perturbation fields effects on H-mode confinement and stability; (2) carry out sensitivity studies of linear M3D-C1 simulations based on device and code dependent parameters such as equilibrium reconstruction variations, single versus two-fluid effects, plasma rotation profile effects and field-error model tolerances; and (3) assess the impact of 3D magnetic perturbation fields and intrinsic field-errors on radiative mantle and divertor detachment physics.

During the last year, the recipient developed an OMFIT workflow for linear/nonlinear multi-mode simulations and studied the impact of M3D mode interactions in single helicity vs. multi-cases. Additionally, the sensitivity of the response model to TF-coil deformations in ITER was investigated, and nonlinear multi-mode MHD modeling was begun to study heat flux spreading.

Summary of Project Activities

This report covers work carried out by the General Atomics recipient between the award date and the recipient's passing in October, 2020. Linear M3D-C1 simulations of an applied n=3 perturbation field in an NSTX-U plasma were studied. Results from these simulations have produced an interesting new type of plasma self-organization process in which magnetic islands undergo an internal bifurcation as the amplitude of the applied n=3 field is increased above a threshold that depends on the normalized plasma beta and the winding number of the bifurcating island. To better understand these results a series of M3D-C1 simulations was carried out in which the thermal conductivity, the flow and the viscosity of the plasma were separately turned off in order to assess the impact of the perturbation field on the MHD plasma response. It was found that turning off the thermal conductivity resulted in the generation of higher-order magnetic structures and turning off the plasma flows resulted in a reduction of the resonant screening on rational surfaces while turning of the viscosity resulted in a failure of the code to run. It was also found that increasing the equilibrium grid resolution allowed us to resolve small, higher order, satellite islands and to change the threshold condition for the internal island bifurcation.

Reduced models of the sheath electric field and radiative deuterium cooling in the divertor were formulated and are being implemented in a kinetic ion thermal transport module in the MAFOT code which is used to calculated the drift-orbit heat flux distributions on the divertor target plates of thermal ions for the core plasma. This code is being developed to test a hypothesis made under this grant that the lack of heat flux splitting due to the formation of separatrix tangles can be mitigated by up-stream radiation due to the recombination and charge exchange of deuterium as the ions enter the divertor region.

A numerical model describing the formation, propagation and recovery of an inward traveling ballistic cold front initiated in the pedestal of an H-mode by an ELM has been developed and compared to experimental measurements in DIII-D. The model predicts a propagation velocity, based on the ion sound speed, that agrees to within a factor of 2-3 with the measured 410 to 510 m/s range of the cold front propagation velocity between the edge of the plasma and the q=3/2 surface.

The major tasks that the GA recipient was involved with modeling plasma response to non-axisymmetric magnetic field perturbations were providing numerical modeling and theory input on magnetic spectra and field line tracing simulations using the TRIP3D-CPU, TRIP3D-GPU, SURFMN and PROBE-G codes, based on simulation results from the M3D-C1 and M3D MHD plasma response codes.

What was accomplished by GA recipient

During the past year of this grant, there was a significant reliance on remote meetings for the DIII-D team due to the COVID pandemic. Previously, T. Evans had used vacuum modeling to study divertor footprint changes and heat flux spreading, and he had analyzed intermediate to high n RMPs in DIII-D H-modes with vacuum and linear plasma response models. In the past year, the recipient facilitated the linear M3D-C1 simulations of multi-mode perturbations by developing an OMFIT workflow for linear/nonlinear multi-mode simulations. Additionally, the impact of M3D mode interactions in single helicity vs. multi-cases was studied. Finally, the effects of TF-coil deformations in ITER on the sensitivity of the response model was investigated, and nonlinear multi-mode MHD modeling was begun to study heat flux spreading.

The recipient's contributions to this project ended in October, 2020, due to their passing away. Before his passing a journal paper with T. Evans as first author was published in Phys. Rev. E on "Observations of heteroclinic bifurcations in resistive magnetohydrodynamic simulations of the plasma response to resonant magnetic perturbations."