Integrated Computing Initiative To Predict Fusion Device Performance and Study Possible Improvements

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The exponential growth of computer power (a factor of a million in the past 30 years, with more to come), combined with major advances that have been made in our ability to simulate key aspects of plasmas in fusion devices, has led many people to conclude that the time is ripe for an initiative to develop integrated computer simulations of fusion devices. There are now detailed 5D gyrokinetic simulations in the main core region of tokamaks (r/a < ~0.9) that can predict fluctuation spectra and turbulent transport fairly well in many regimes. The general feasibility of calling short time scale gyrokinetic turbulence codes within long-time-scale transport codes has been demonstrated, using massively parallel computers and implicit projective integration algorithms. However, these simulations need to use measured boundary conditions (or semi-empirical models) at r/a ~ 0.9 and so are not yet fully predictive. One of the biggest remaining challenges is to develop gyrokinetic simulations that can handle the additional complexities of the pedestal/SOL edge region (r/a > ~0.9). These are very hard problems, but progress is being made, and the success of core gyrokinetic simulations gives us encouragement that a significant initiative should be able to develop codes to simulate the edge as well.

While we believe this is feasible, much work remains to develop integrated computer simulations with a fully predictive capability. Besides developing codes that are complete enough to successfully handle the edge region, more work is needed to understand different types of core and edge turbulence, to test these codes against experiments in a wider range of parameters, and to improve some of the source and sink modules. Different integrative approaches could be tried, from a more monolithic approach (which tries to include more physics in a single code) to a more distributed framework (where profiles are evolved with small-scale turbulent transport from gyrokinetic modules, and extended MHD modules are periodically called to check large-scale stability and calculate the spreading of energetic particles). An integrated simulation initiative would have a modular framework so that different options can be used for different purposes. Independent modules need to be developed to cross-check each other and find efficient algorithms for different problems. Reduced transport models would be used in interpretive and predictive runs for fast turn-around for discharge analysis, transport model validation, and shot scenario development and prediction. Such tools would be used for an extensive validation campaign comparing with present experiments, and would then be used to make projections to future devices. Every shot on ITER will first have to be simulated with these types of codes, to predict if they will avoid disruption limits. This initiative will build on US leadership in general computing and in advanced fusion simulations.

The FESAC Strategy panel has been hearing about a number of innovative ideas for improving fusion (including liquid metals, advanced tokamak and ST regimes, new divertor and stellarator designs, and high field superconductors). The goal of a major computational initiative would be to develop comprehensive simulations within five years that are well tested against experiments, that can be used to help evaluate and optimize these innovative concepts, and that can help make a strong case for the next steps in fusion research.