Integrated Simulations

Topical area of White Paper: Whole device modeling

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In his March 12, 2015 presentation to FESAC, Edmund Synakowski outlined the five major considerations for Congressionally-mandated ten-year plan for the Fusion Energy Sciences program. His list began: "*First, massively parallel computing with the goal of validated whole-fusion-device modeling will enable a transformation in predictive power, which is required to minimize risk in future fusion energy development steps*."

Having theory and computation elevated to the first consideration for the ten-year plan is appropriate--especially in a period of constrained financial resources. Theoretical research requires few resources but has many implications. The low cost of theory compared to experiments implies that theory funding should be set by the quality of the ideas and on the expected reliability.

Although theory and computation can provide answers to many, they cannot provide reliable answers to all questions of importance to the fusion program. The determination of which important questions can be reliably answered by theory is the central issue in strategic planning.

Despite their importance, integrated simulations have three pitfalls, which must be avoided: (1) They may be possible but far more complicated than required. Simulations may be analogous to using many-body quantum calculations to study the elementary electrical properties of an object rather than a simple Ohm's law. (2) They may require unreliable ad-hoc assumptions to obtain a complete set of equations. A fully integrated simulation is only as reliable as its least reliable assumption. (3) They may not include all of the important dimensionless parameters in their relevant regimes.

The pitfalls of integrated simulations can only be avoided by a careful comparison of simulations to the constraints of physics. Validation of theory by observations is useful but not adequate. Ptolemy's geocentric model had fourteen hundred years of success in predicting eclipses and the positions of planets in the sky despite inconsistency with the laws of mechanics.

The most reliable answers are those that can be based on Maxwell's equations. For a number of the most important questions that must be addressed by the fusion program, the details of plasma physics are irrelevant---the plasma can be viewed as a black box, which interacts with the outside world through Maxwell's equations. This is particularly important for the study on the effects of non-axisymmetry and was the organizing principle of my review, Nuclear Fusion **55,** 025001 (2015). It has not been customary to make a clear distinction between calculations that are possible using only Maxwell's equations and those requiring detailed plasma calculations. The separation is analogous to the study of the electrical properties of an object using its the resistivity η and permittivity ε to sidestep the many-body quantum calculation that would be required to explicitly calculate η and ε.

Although the goal of whole device modeling through integrated simulations is laudable, this goal should not be pursued in a manner that impedes obtaining reliable theory and computational answers to the most important questions that are faced by the fusion program.