The role of integrated modeling in disruption avoidance and profile control development

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Research in the US after the ReNeW has given much emphasis on optimizing flattop scenarios as a way of avoiding disruptions, indeed with very good results, both in experiments and simulations. For example, steady-state exploration in DIII-D, operational scenario development of NSTX-U, ideal MHD stability evolution of ITER steady state scenarios. Both experiments and simulations over the years have indicated that broad current and pressure profiles are desirable for ideal MHD stability. Hence a need for profile control.

The role of integrated modeling in this research is to identify critical paths by complementing experiments, since the achievement of a discharge with zero disruptivity heavily relies on the design of discharges that are safe, from startup to plasma shut-down, thru a well designed control system that accounts for all the complex interplay among actuators.

The effect of actuators on the evolution and MHD stability of the plasma can and should be explored in simulations before it is tested in experiments, especially in phases of the discharge where parameters continuously change in time, like the ramp-down. Time-dependent transport solvers like TRANSP are particularly suitable to this purpose because they allow testing the physics principles of control algorithms in experimental-like conditions and with high-fidelity transport and heating and current drive modules. This is done by means of so-called 'expert files', user-defined scripts that can be called in specific places during the simulation to execute pre-defined calculations and actions. Examples of expert-files that have being implemented in TRANSP over the past two years for control purposes include plasma rotation control, shape and current control, density feedback, real-time control of Electron Cyclotron heating.

High fidelity discharge evolution relies on high fidelity models for core thermal and particle transport, Heating and Current Drive actuators, bootstrap current, edge physics and reduced MHD. High fidelity physics does not necessarily mean that the modules in a WDM have to be first principle physics codes, but that they have to include the important physics to describe a large variety of operational parameters.

Short-term priorities should include:
- validation of core thermal transport models on various operational regimes, at least on the three national tokamak devices.
- further implement reduced models, based on the result of this validation. There might be a need of repeating what has been done for TGLF on a larger database of parameters, if validation indicates that existing reduced models have no broad application.
- develop and validate reduced models for the ramp-up phase, since no model can adequately reproduce L-mode, low-current experiments.
- integrate impurity transport models in time-dependent simulations and validate on existing experiments, for both low-Z and high-Z impurities. Codes that would be suitable for implementation in a WDM are COREDIV (by Zagorki) and STRAHL (by Dux), both Europeans.

Medium-term priorities should include
- core-edge-SOL coupling
- reduced MHD stability codes, at a minimum for sawtooth and Neoclassical Tearing Modes.

Edge physics codes, like SOLPS and UEDGE, are computationally extensive. Perhaps they can be used offline to run parameter scans and build large databases that can then be used to derive reduced models or look-up tables that can then be integrated into time-dependent simulations. This might not be a finalized approach, but it might be a starting point for validations, to which complexity can be incrementally added.

MHD stability calculations have a similar role. Although it is not feasible and not desirable that complex MHD codes are directly included in a time-dependent simulation, these codes should provide a base for the construction of reduced models that can be used for simulations. When it comes to disruption avoidance thru control, MHD codes are valuable to identify precursors to disruptions and their evolution time-scale. This is the first step to understand how they can be detected in real-time and how they can be incorporated in a control scheme.

Long-term priorities should probably focus on optimization of performance of these codes, aiming at reducing computational time, by means of parallelization and algorithm improvement.

It is likely that integrated modeling, as a Whole Device Model, will evolve together with experimental needs and with availability of new modules, as they come. Whatever the decision of this panel is regarding priorities, it should leave open possibilities on how various modules are integrated. It is likely that, to accommodate the increasing need for fast calculations and in-between shot analysis, some of the existing modules will leave room to reduced models. This is going to happen on long time scales, and it is the final process of extensive and systematic validation exercises.