Fusion Simulation Project - JET Experience

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We were very glad to see the first report of the FESAC ISOFS Subcommittee since it addresses issues, which are very close to our own experience on integrated analysis and predictive modelling of JET plasmas. We therefore think that JET experience would be of interest to our American colleagues and this was the main motivation behind this comment. Please note that this commentary reflects personal opinion of the author, rather than a common view of JET community.

One of the most significant transformations, which JET experienced since the end of JET Joint Undertaking in 1999, is that all European Associations get direct access to the JET database and all associated tools for data analysis and modelling. Now all interested members of European Fusion Laboratories (and many American physicists as well) can not only participate in JET experiment on cite, they can remotely access JET database and work with this database and all analysis and modelling tools from their home Institutions. This transformation encourage theoreticians and modellers from other European Fusion Laboratories to work with JET data as well as to share associated analysis and modelling tools. Recently organised Task Force-T (Transport) gave this area an official status and brought some additional money into theoretical and modelling activity.

Since the author of these notes is primarily involved into the area of predictive modelling, we will concentrate on this subject putting aside a very important discussion of the structure of JET database and tools for data analysis. The only one statement concerning JET database, which I would dare to make, is that, in my opinion, JET has one of the best and probably the most accessible experimental database in the world. All JET data are stored in a commercially supported database, which is equipped with all necessary viewing facilities and tools for data analysis and modelling. And all of these facilities are available for remote users.

Predictive modelling is an integral part of data analysis actively used at JET. Modelling activity is split into two parts: code development and maintenance and modelling itself. Code development and management belongs to JET Operational Contract, run by the UKAEA. Modelling of JET plasma is a joint activity, run by Associations.

The following tools are available for the modellers both on-cite and remotely:

- 1.5D core transport code JETTO. It's a versatile tool similar to American codes TSC, BALDUR, CORSICA etc. The code is linked with JET database and it allows storing the results of the modelling in the database in the same format as experimental data;
- 2-D transport code EDGE-2D, which simulate plasma and neutrals in the SOL. The code is linked with JET database and it generates the output in the format, which allows direct comparison with some "unusual" diagnostics (like electrostatic probe measurements). It is similar in many respects to other 2-D codes like B2 and UEDGE;
- JETTO and EDGE-2D are linked together (with an interface positioned a bit inside the separatrix). The combined code COCONUT provides simulation of the whole plasma from the hot core up to the target plate and it manages to cover a

very wide range of characteristic time scales (from $\tau_{\min} \le \frac{qR}{V_{Ti}} \propto 10^{-4}$ sec to $\tau_{\max} \ge \tau_E \propto 1\sec$);

- We have a number of Linear MHD Stability codes, which are linked with JETTO (IDBALL for ideal ballooning, MISHKA for finite-n ballooning, peeling and kink modes). The codes use pressure and current profiles, generated by JETTO as well as self-consistent fixed-boundary equilibrium from JETTO;
- We have a number of either stand alone or linked with JETTO NBI and RF Heating and CD codes similar to those used in the US;

We do not have (or do not use in our modelling):

- Non-linear gyrokinetic or particle-in-cell code for core turbulence;
- 3-D non-linear MHD code;
- Free boundary equilibrium code (we have EFIT and other free boundary codes on JET, but we do not use it self-consistently with JETTO).

It made a very right statement in the Executive Summary of the First Report of the FESAC ISPOS Subcommittee that "Two fundamental issues are common in many fusion physics integration areas: coupling of phenomena at disparate space and time scales, and coupling models of different dimensionality". Another issue of extreme significance is the fact that many experimentally observed phenomena cross theoretical boundaries and require complex, "integrated" approach, which is still not common in predictive modelling. We realise an importance of such integrated approach and are dealing with these issues for a number of years. Below we give just one example of our present activity, which addresses the issues of pedestal physics. This area, in your definition, belongs to a small number of proposed Focused Integrated Initiatives.

- We use transport code JETTO to simulate core plasma. Unlike other modelling groups, we include edge transport barrier into simulation.
- We assume that all anomalous transport within the barrier is suppressed so that the only remaining transport is neo-classical (comes from NCLASS);
- ETB width is prescribed using theory based models (M. Sugihara et al., A. Kritz et al.,);
- Since both pressure and current profiles within ETB (those profiles which control MHD stability) depend sensitively on the boundary conditions on the separatrix (including influx of neutrals), we link JETTO with 2-D SOL transport code EDGE-2D. This coupled code COCONUT deals with a wide range of physics processes, which include anomalous core transport, longitudinal transport in the SOL, atomic physics and MHD stability;
- To address MHD stability issue, JETTO has been linked with the linear MHD stability codes IDBALL and MISHKA (the latter is very similar to ELITE code, better known in the US);
- MHD stability codes get self-consistent information about pressure, current profiles and equilibrium from JETTO and return results of stability analysis back to JETTO. However JETTO does not use these results directly (because of disparity in CPU time). Instead, JETTO uses some simplified analytical formulas

for MHD stability, which are adjusted in accordance with the results from MHD stability codes;
- To simulate ELMs, JETTO increases temporarily all transport coefficients within ETB if a MHD stability criterion is violated. This removes excessive pressure and current and then the cycle repeats.

A number of important issues have not been addressed in out modelling and require further efforts. These include:
- Longitudinal transport in the SOL is fluid, which is not a good approximation for high temperature, low density SOL;
- ELM description is heuristical, we need more input from non-linear MHD theory;
- ETB formation is an ad-hoc rather than theory based process.

The list of such unresolved issues can be extended. But these issues are part of what is usually called "work in progress" so we are dealing with these issues in a due course. Instead I would like to mention here some general problems, which we experience in our work and which might seriously affect FSP as well:

- The main problem of "integrated modelling" is in effect very similar to the problem of "integrated experiment"- it's a shortage of qualified physicists who are specialists in more than one area of plasma physics. It is well known that JET has a number of task forces, which deal with separate issues (ELMy H-mode, plasma with internal barriers, MHD, heating and so on). These task forces have the same problem as theoreticians: they know very little about what other task forces are doing. There is apparently a lack of motivation and encouragement for the younger people to widen their scientific horizon. Somehow this motivation should be enforced.
- Second problem is that until now predictive modelling was considered as an activity, inferior to both theory and experiment. Widely used in the past empirical transport models is probably one of the reasons to blame. At present theory based transport models are easily available (although they have not converged into one universally accepted model yet). This makes predictive modelling much trustworthier than before. One should realise however that full prediction of plasma performance is an ultimate goal of predictive modelling. Until then integrated modelling will always use some simplified (although theory based) models for complicated physical phenomena. And as such comparison with experiment will remain one of the most important tasks for integrated predictive modelling.
- The issue of comparison with experiment has another important side. History of fusion shows that successful large-scale experiment (accompanied by good, easily accessible database) usually attracts theoreticians and modellers as well as experimentalists. This results in a fruitful exchange of information and ideas and leads to a fast progress in experiment, theory and modelling. Let me make it clear: I am against any monopoly in science. But simultaneously I think that lack of communication leads to a serious deficiency in our research. Therefore I think that FSP should foresee some "focal point" where experimentalists, theoreticians and modellers could freely discuss their work. In my opinion, it would be natural to associate such "Information Centre" with one of the large experiments.
- Forth is the problem of the multiplicity of available transport codes. It's a historical fact that different Institutions use different transport codes. There is

nothing wrong with it as long as these codes are used locally (and as long as Institutions can afford maintaining such multiple codes). The real problem arises when all these codes are being brought together and tried to be used for the same database (that's what actually happened at JET). Our first notion was to try to make one code (or suite of codes: COCONUT in our case) available to all users, including those who work with codes remotely from Associations. However we can't really say that this approach was a success. Indeed, it worked fine for smaller Associations, who did not have their own facilities. Others still prefer to use their own codes (even if these codes are not properly linked with JET database). Now we think that the only way towards unification is bringing people together under one initiative (working towards ITER might be a natural choice for European physicists).

- Finally it should be realised that integrated predictive modelling was always poorly funded. The result is that there is not so many specialists working in this area. And those who do work are isolated and do not have enough forums for discussion and competition. Therefore I think it's vitally important to enforce an organisation of proposed Focused Integration Initiatives with the proper budget and solid structure.