

Non-linear MHD code development for ELM simulations

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In recent years some progress has been made in the numerical simulation of Edge Localised Modes (ELMs) by means of non-linear MHD simulations of medium-n ballooning modes [1-4]. The MHD simulations are essential to improve our understanding of the physics of the ELMs (the onset, the amplitude of the crash, etc.) in view of the extrapolation to ITER and the control of ELMs. However, the simulation of a full ELM cycle remains an open problem.

The first ballooning mode simulations with the non-linear MHD code JOREK [4] used a very limited number of toroidal harmonics. In order to improve the resolution, the JOREK code has been undergone a significant development. The MHD variables and the (R,Z) space coordinates are discretised using the newly developed isoparametric bicubic Bezier finite elements [5]. This allows an accurate alignment of the finite elements to the flux surfaces on the closed and open field lines. The alignment and the higher order elements are necessary to be able to treat a high anisotropy of the parallel to perpendicular heat conductivity.

The time stepping scheme in the new version of the JOREK code remains fully implicit. In addition to the direct solver (Pastix), an indirect solver (GMRES) has been implemented using the sub-matrices of each toroidal harmonic as an efficient pre-conditioner. This improves the scalability of the parallelisation of the code and alleviates the memory requirements of the implicit solver. The parallelisation efficiency is satisfactory up to at least 512 processors.

In parallel, the code Fluidbox, a more general purpose CFD code, is being extended to include the full MHD model. Fluidbox uses a different numerical method: triangular type meshes (2D and 3D) and a stabilised residual distribution method [6] that is able to handle strong gradients. The $\text{div}(\mathbf{B})=0$ condition is handled with a Lagrange multiplier technique. The code is implicit, fully parallel and uses the parallel Pastix [7] linear algebra library.

The first application of the new JOREK code has been to extend the earlier calculations to a higher resolution using toroidal harmonics up to $n=0$ to 33 with a periodicity of 3. The interaction of a range of unstable ballooning modes leads to a localisation of the instability in the poloidal and toroidal directions. The equilibria with a pedestal in x-point geometry are characterised by a large poloidal flow close to the separatrix. The influence of the poloidal flow on the MHD stability and non-linear evolution is investigated.

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