Simulation of pellet cloud drift with Multileved 3D code(M3D)

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Pellets are injected into thermonuclear devices for refueling, diagnostic use, or for quenching the plasma prior to hard disruptions. A pellet injected into a hot plasma ablates at a rate defined by the balance of energy flux reaching the pellet surface. The ablated particles form a cloud around the pellet, cloud expands unimpeded as long as the particles remain un-ionized, and it is continuously heated by collisions with incident energy carriers. At some time instant ionization sets in at the cloud periphery, the ionized particles interact with the magnetic field and their motion becomes magnetically constricted. As the pellet traverse the magnetized hot plasma high-beta plasmoids are formed along the pellet path. Therefore in addition to the conventional ablation processes- dominated by neutrals, electrostatic, and plasma shielding, these plasmoids may further penetrate due to drift effects, before are stopped by magnetic forces or are disperse along field lines due to parallel dynamics. Recent experiments of high field side pellet injection, have demonstrated the grad($\mathbf{B}$) -caused drifts. These drifts can transport the pellet cloud to regions that are not traversed by the pellet path. Hence the interaction of injected pellets with hot magnetized plasmas is a truly three dimensional problem. The prediction of particle deposition profiles in future fusion devices such ITER is of overwhelming importance.

In order to proceed towards realistic pellet-plasma simulation studies we are interfacing pellet ablation modules[1] to a nonlinear 3-D MHD code[2].

Method

A time dependent quasi-three-dimensional code [1]which calculates all major characteristics of the pellet ablation process and accounts for the expansion of the cloud and the motion of the pellet, has been developed. Modules of this code are being coupled to the nonlinear 3-D MHD code M3D to study the expansion dynamics of pellet clouds in truly 3D magnetic fields. The M3D code is a multilevel MHD code in 3-D, with an unstructured triangular grid in the poloidal plane, and prism elements in the 3-D space The M3D code has been used for studies of pellet driven disruptions in tokamaks[3].

The coupling of the two codes is as follows: a pellet is injected into a torus with certain velocity along a prescribed flight path. As the pellet traverses the torus(simulated by the M3D code) the pellet resides along its path at discrete positions for certain residence times. During these residence times M3D provides the parameters of the background magnetized plasma and the ablation code is used to calculate the formation of a confined ‘plasmoid’ around the ablating pellet. These plasmoids, aligned with the magnetic field lines, are then transferred to the M3D code which computes the further evolution of these local massive disturbances.

For our studies of pellet-plasma interaction in real tokamaks (for example ASDEX Upgrade) we have interfaced M3D with the DIVA[4] equilibrium code. The initial conditions of the M3D code prior to the pellet injection: Ψ, plasma pressure , plasma current density, and the numerical grid, are taken from the DIVA code , see Figure 1. DIVA calculates separatrix or limiter defined, static and stationary equilibria in the magnetic fields of an external conductor system. Due to its object-orient design with object persistency DIVA easily transfers plasma equilibria on triangulated domains by exporting a corresponding class. On the other hand, owing to the implementation of unstructured meshes in M3D in C++, the M3D code can also easily import these equilibria by making them a data member of one of its classes.

Preliminary results and discussion

The reduced set of equations of M3D are used in the following numerical experiment. An equlibrium of ASDEX Upgrade (shot 14023 at 2.395 s, $I_p = 1$ MA, $\beta_p = 0.738$, q(95%) = -3.768) is imported by M3D . To this equilibrium a cylindrical pressure perturbation , of 2cm radius, and equivalent to $\beta = 0.3$ is deposited at $R = 1.4m$ and $Z = 0$, the M3D is then allowed to evolve. Global refiniment, all triangles are splitted into four trianges, to the mesh obtained from DIVA is applied prior to the use by M3D.

In the preliminary results presented here the M3D was allowed to evolve for several hundreds of time steps. The units that the results are presented are in non-dimensional units used by M3D. Figure 2 displays the contours of q as reconstructed by M3D. Figures 3 and 4 show the pressures profiles. Figure 5 display the flux surfaces. Figure 6 shows the contours of the toroidal plasma current density. Figure 7 displays the electric potential, and Figure 8 shows the vorticity.

In order to deposit plasmoids, from the ablation modules to the M3D code, which have stopping radii of 1cm and less, finer grid must be used. We intent to proceed with adaptive grid refinement in the poloidal plane and non-uniform gridding in the toroidal direction. This refinement must be done between flux surfaces and not only around the pellet cloud, because of the parallel dynamics. We also intent to proceed with the full set of the M3D equations for our pellet-plasma interaction studies.

References

[2] L.L. Lengyel, et.al. Nucl. Fusion **39** (1999), 791.

[1] W. Park, et.al., Plasma simulation studies using multileved physics models, **6**, (1999), 1798.

[3] H.R. Stauss and W. Park, Pellet Driven Disruptions in Tokamaks. Phys. Plasmas **7**, 250 (2000).

[4] H.P. Zehrfeld, Resistive Equuilibrium Sates of Axisymmetric Plasma with Compressible Viscous Fluid Flow, in 26th Conference on Controlled Fusion, Maastricht, Netherlands, 1999.

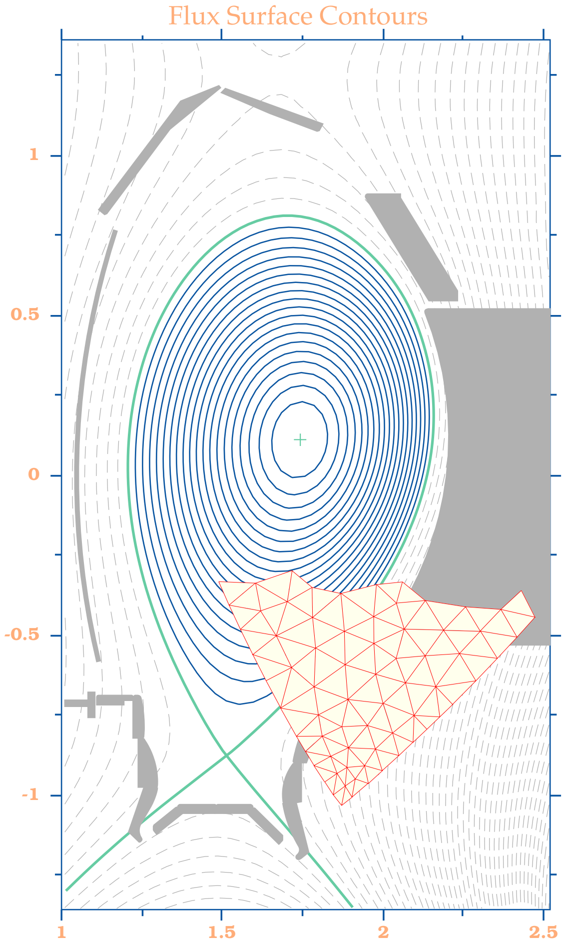

Figure 1: Flux surfaces of ASDEX Upgrade and an exploded view of the triangulated region near the x-point.

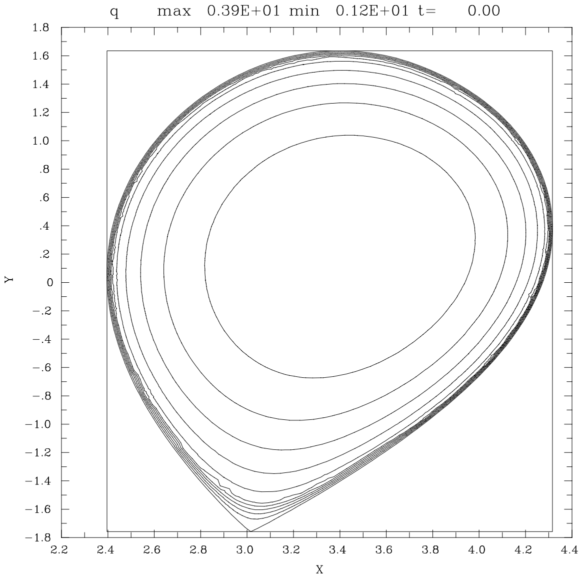

Figure 2: Contour plots of q .

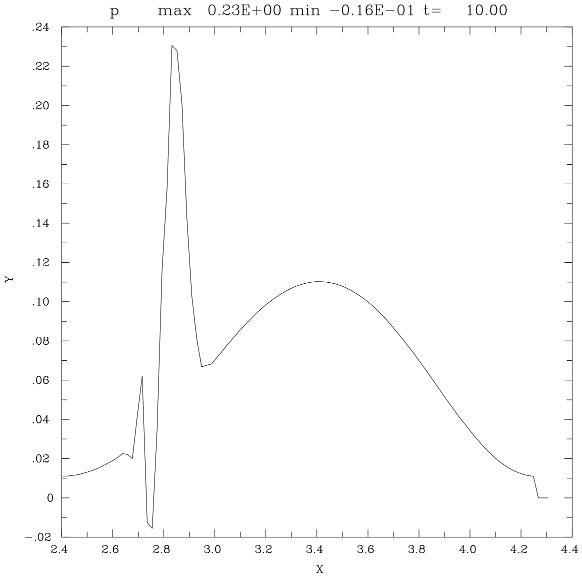

Figure 3: Profile of the plasma pressure at Z=0 and along R, with an initial pressure perturbation of 0.3 beta.

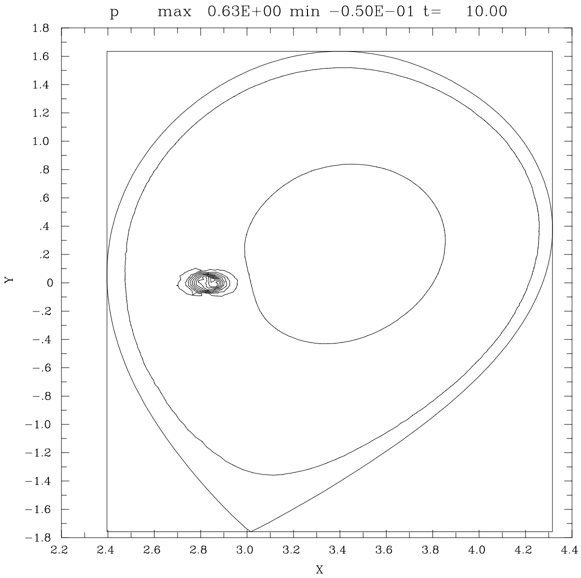

Figure 4: Contour plots of plasma pressure, nondimensional units.

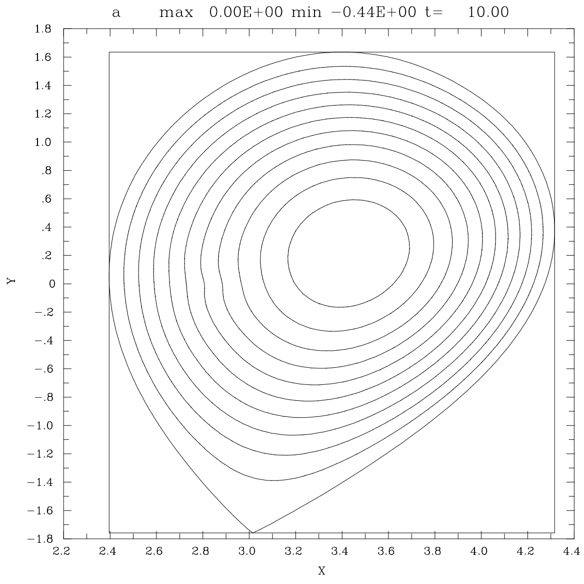

Figure 5: Flux surfaces in nondimensional units from M3D.

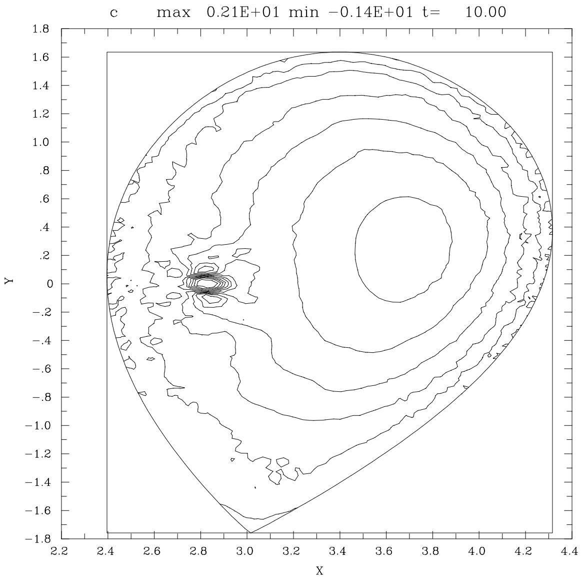

Figure 6: Contour plots of toroidal current density .

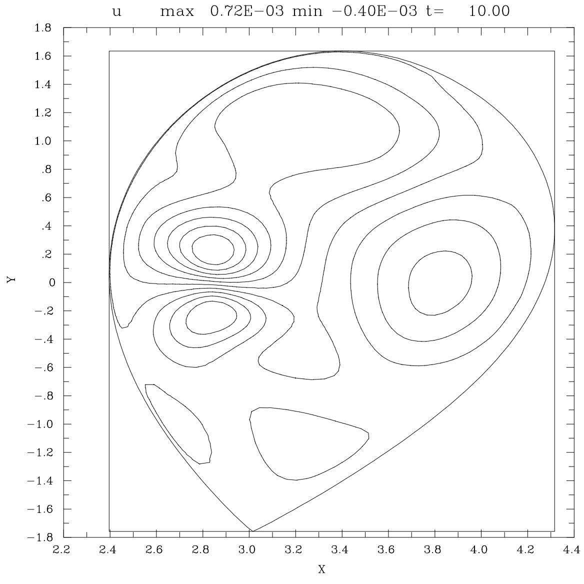

Figure 7: Contour plots of the electric potential.

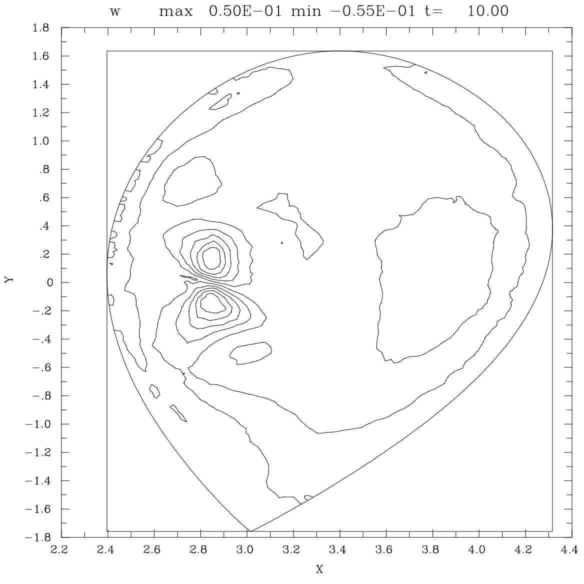

Figure 8: Contour plots of vorticity