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Development of a far-SOL unstructured-mesh fluid-plasma transport solver for RF antenna simulations

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A new fluid plasma transport solver MAPS (MFEM 1 Anisotropic Plasma Solver) is being developed for the simulation of far scrape-off-layer (SOL) radio frequency antenna simulations. MAPS solves a coupled set of particle, parallel momentum, and energy equations for plasma and neutral species using a finite element approach based on the MFEM (Finite Element Discretization Library) framework 1. The code uses a generalized implementation supporting 2D or 3D geometries on an unstructured mesh, allowing for a grid that conforms to complicated far-SOL antenna and limiter structures. The highly anisotropic plasma transport is addressed via the use of high order finite elements, as used in extended MHD codes [2,3]. This choice of numerical methods can support cross-field drifts and kinetic corrections, which are typically neglected in 3D fluid plasma transport codes. The development of MAPS will lead to important verification tests with the leading 3D edge fluid plasma code EMC3-EIRENE [4], which uses a field-aligned mesh and a Monte-Carlo numerical method to handle the transport anisotropy.

MAPS solves continuity equations for a fluid neutral atom species and a single hydrogenic ion species, a total plasma parallel momentum equation, and energy equations for electrons and ions (the latter two in the form of static pressure evolution). A simplified set of these equations is written as

$$\frac{\partial}{\partial t}n_n = \nabla\cdot(D_n\nabla n_n) - S_{iz}$$
$$\frac{\partial}{\partial t}n = -\nabla_{||}(nv_{||}) + \nabla_\perp\cdot(D_\perp\nabla_\perp n) + S_{iz}$$
$$\frac{\partial}{\partial t}mnv_{||} = \nabla\cdot(\bar{\bar{\eta}}\cdot\nabla v_{||}) - \nabla_{||}(p+mnv_{||}^2) + \nabla_\perp\cdot(mv_{||}D_\perp\nabla_\perp n)$$
$$\frac{3}{2}\frac{\partial}{\partial t}p = \nabla\cdot(n\bar{\bar{\chi}}\cdot\nabla T) + \nabla_{||}p - \frac{5}{2}\nabla_{||}pv_{||}$$
$$+\frac{5}{2}\nabla_\perp\cdot(n\chi_\perp\nabla_\perp T) - \frac{D_\perp}{n}\nabla_\perp n\cdot\nabla_\perp p + S_E$$

where cross-field drifts, volume recombination, and electric fields are currently neglected. The static pressure equation is the same for electrons and ions, with an appropriate source term S_E for each species (equipartition and terms due to plasma-neutral interactions). The diffusivity tensors $\bar{\bar{\eta}}$ and $\bar{\bar{\chi}}$ have the form $\bar{\bar{D}} = D_\perp(\bar{\bar{I}} - \bar{b}\bar{b}) + D_{||}\bar{b}\bar{b}$ with the parallel components from classical theory and ad-hoc cross-field components. The particle source is S_{iz}, with neutral atoms taken to have a constant energy of ~3 eV. The transport equations are discretized using discontinuous Galerkin finite elements of arbitrary order. Time integration uses high-order singly-diagonally implicit Runge–Kutta (SDIRK) methods, with a novel time step selection using a PID controller [5]. Adaptive mesh refinement is based on a weighted error estimate of each field.

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The anisotropy in the plasma transport is addressed by the use of high order finite elements. The method has been benchmarked against a general anisotropic diffusion equation test problem, as described in Ref. 4. Acceptable levels of numerical pollution of the cross-field transport are obtained for a diffusivity ratio of 106 - 109 using finite element orders > 2. The results also depend on the grid resolution [5]. Figure 1 shows results from a test problem where a constant temperature field on closed magnetic flux surfaces is perturbed by a Gaussian energy source. Acceptable levels of pollution are found for finite element orders > 2 with > 16 interpolation points across the feature of interest. The anisotropy benchmarks exhibit good behavior at extreme diffusivity ratios that can exist in the core of tokamak plasmas, however the target problem of far-SOL simulations will exhibit significantly lower anisotropy.

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The full set of transport equations in MAPS is currently being benchmarked against a 2D fluid plasma transport code developed to study island transport in LHD [6]. Figure 2 shows a comparison of MAPS and analytic solutions for simple transport in an annular cylindrical geometry. Comparison for a more complicated case with an imposed island chain [6] is in progress. Further extensions of the code include the addition of an electric potential equation using the approach employed in BOUT++ [7]. Following this, MAPS will be coupled to a wave solver to explore issues of RF-plasma coupling, the effect of the ponderomotive force, and the impact RF-enhanced sheaths on divertor fluxes and sputtering. A natural coupling is to the MFEM Stix miniapp 1, also under development as part of the RF-SciDAC.

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1 MFEM: Modular Finite Element Methods Library, mfem.org, doi.org/10.11578/dc.20171025.1248
2 S.C. Jardin, J. Comp. Phys 200 (2004) 133.
3 C.R. Sovinec, et al., J. Comp. Phys. 195 (2004) 355.
4 Y. Feng, et al., J. Nucl. Mater 266 (1999) 812.
5 M.L. Stowell, et al., APS-DPP, Portland OR, 2018.
6 M. Kobayashi, et al., PET conference, San Diego CA, 2019.
7 N.M. Li, et al., Comp. Phys. Comm. 288 (2018) 69.

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