**FLUID, KINETIC AND HYBRID APPROACHES FOR EDGE TRANSPORT MODELLING IN FUSION DEVICES**

An overview of the efforts to improve the performance of the key simulation tool for the neutral species in the edge of the fusion devices

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**Introduction**

Neutral gas physics and neutral interactions with the plasma are key aspects of edge plasma and divertor physics in a fusion reactor including the detachment phenomenon often seen as key to dealing with the power exhaust challenge. A full description of the neutral gas dynamics involves the coupling between the fluid and kinetic equations, since the details of the wall geometry play a substantial role, to the extent that, e.g., the divertor region has to be included. The Monte Carlo (MC) approach used for about 30 years in ERIS [1], is well suited to solve these types of complex problems. Indeed, the MC approach allows simulating the 3D kinetic equation without having to store the velocity distribution on a 3D grid, at the cost of introducing statistical noise. MC also provides very good flexibility in terms of density, chemistry and atomic and molecular (AM) processes. However, it becomes computationally extremely demanding in high-collisional regimes (HCR) as anticipated in ITER and DEMO. Parallelization on particle helps reducing the simulation wall clock time, but to provide speed-up in situations where single trajectory potentially involve a very large number of A&M events, it is important to derive a hierarchy of models in terms of accuracy and to clearly identify for what type of physics issues they provide reliable answers. It was demonstrated that advanced fluid neutral (AFN) models are very accurate in HCRs, and at least of an order of magnitude faster than fully kinetic simulations. Based on these fluid models, three hybrid fluid-kinetic approaches are introduced: a spatially hybrid technique (SpH), a micro-Macro hybrid method (mRM), and an asymptotic-preserving MC (APMC) scheme, to combine the efficiency of a fluid model with the accuracy of a kinetic description. In addition, atomic and molecular ions involved in the edge plasma chemistry can also be treated kinetically within the MC solver, opening the way for further hybridisation by enabling kinetic impurity ion transport calculations. This paper aims to give an overview of methods mentioned and suggest the most prospective combinations to be developed.

**Fluid-kinetic hybridisation (FKH) approaches relation and basic theory**

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<tr>
<th>Code performance</th>
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**Fluid-kinetic hybridisation (FKH) approaches relation and basic theory**

**Kinetic ion module (KIM) for Atomic and Molecular (A&M) species**

What is achieved [35]:

- The approach is developed (both SpH and mRM) for the CFD-EIRENE packages [20, 21]. It combines improved computing performance with model accuracy approaching full kinetic simulations.
- The alternative perspective APMC approach is also considered [21], including development and first tests of the newly proposed RCMC formulation with a multinormal overlap option [24] aimed to overcome the expected limitations.
- The advantage of hybridisation methods is apparent based on experience from the first applications to test cases involving molecular processes. Currently, these include:
  - basic development of the approaches
  - relative with full kinetic simulations to determine the gain in computational speed-up and optimal parameters
  - impact demonstration of new physics included on, for example, ITER-relevant applications

**Summary & Conclusions**

- A FKH approach is developed (both SpH and mRM) for the CFD-EIRENE packages [20, 21]. It combines improved computing performance with model accuracy approaching full kinetic simulations.
- The alternative perspective APMC approach is also considered [21], including development and first tests of the newly proposed RCMC formulation with a multinormal overlap option [24] aimed to overcome the expected limitations.
- The advantage of hybridisation methods is apparent based on experience from the first applications to test cases involving molecular processes. Currently, these include:
  - basic development of the approaches
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- The hybrid OpenHDF-MPI code parallelisation and optimization of the A&M process treatment improved CRMs go mostly in parallel adding an additional factor to the improvement of the EIRENE-NGM performance. However, this factor can depend on the first selection of the FKH scheme and overall optimisation of the code.