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A benchmark between HYMAGYC, MEGA and ORB5 codes using the NLED-AUG testcase to study Alfvenic modes driven by energetic particles

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One of the major challenges in magnetic confinement thermonuclear fusion research concerns the confinement, inside the reaction chamber, of the energetic particles (EPs) produced by fusion reactions and/or by additional heating systems, as, e.g., electron and ion cyclotron resonant heating, and neutral beam injection. In such experiments, EPs, having their velocities of the order of the Alfven velocity, can resonantly interact with the shear Alfven waves. In order to predict and, eventually, minimize the Energetic Particle (EP) transport in the next generation fusion devices, several numerical models, based on different theoretical approaches, have been developed. In this respect, it is crucial to cross verify and validate the different numerical instruments available in the fusion community. For this purpose, in the frame of the Enabling Research project MET [1], a detailed benchmark activity has been undertaken among few of the state-of-the-art codes available to study the self-consistent interaction of an EP population with the shear Alfven waves, in real magnetic equilibria in regimes of interest for the forthcoming generation devices (e.g., ITER [2], JT-60SA [3], DTT [4]). The codes considered in this exercise are HYMAGYC [5], MEGA [6], and ORB5 [7, 8], the first two being hybrid MHD-Gyrokinetic codes (bulk plasma is represented by MHD equations, while the EP species is treated using the gyrokinetic formalism), the third being a global electromagnetic gyrokinetic code (both bulk and EP species are treated using the gyrokinetic formalism). The so-called NLED-AUG [9] reference case has been considered, both for the peaked off-axis and peaked on-axis EP density profile cases, using its shaped cross section version. This case poses an exceptional challenge to the codes due to its high EP pressure, the rich spectrum of experimentally observed instabilities and their non-linear interaction [10].
Particular care has been devoted to consider plasma and numerical parameters as close as possible among the three codes: the same input equilibrium file (EQDSK) has been considered, ion density profile has been obtained by imposing quasi-neutrality ($Z_i n_i + Z_H n_H = n_e$), as required by ORB5 (here n_i, n_e, n_H are the bulk ions, electrons, and EP densities (both bulk ion and EPs are assumed to be Deuterons), respectively, and Z_i, Z_H their electric charge numbers); finite resistivity and the adiabatic index, $\Gamma = 5/3$, have been assumed for both the hybrid codes (this is the usual choice used in MEGA, where also some viscosity is considered to help numerical convergence; note that HYMAGYC do not include viscosity).
Only finite orbit width (FOW) effects has been retained for now, and an isotropic Maxwellian EP distribution function of Deuterons with T_H=93 keV, constant in radius, has been considered.
Perturbations with toroidal mode number n=1 will be considered; the results of simulations considering both off-axis and on-axis peaked EP density profiles will be presented. First, simulation results referring to the linear growth phase will be considered.
For the peaked off-axis EP density profile case the three codes give very similar results (note that for MEGA, two MHD models are available, the 'Standard MHD' model and the 'Hazeltine-Meiss MHD'[11] model). The dominant drive comes from the positive gradient portion of the EP density profile, $0. \leq s \leq 0.4$ ($s \propto \sqrt{\psi}$ is the normalized poloidal flux function). The radial profile of the poloidal components of the eigenfuncion (see Fig.1), as obtained by the three codes compare quite well, the most unstable mode being located radially close to the magnetic axis, around $s \approx 0.2$, and in frequency within the toroidal gap.
Moreover, HYMAGYC and MEGA (both models) show a very similar growth-rate dependence on the ratio of EPs to bulk ion densities, n_H/n_i, while ORB5 exhibits some stronger dependence. Also, the results of varying the EP temperature will be considered.
Similar analysis have been performed for the peaked on-axis EP density profile case. Frequencies of the most unstable mode found by all codes have opposite sign, w.r.t. the off-axis case; eigenfunctions for HYMAGYC, MEGA-'Standard MHD' model and ORB5 are quite similar (they correspond to a mode located at $s \approx 0.4$, slightly inside the radial position where the q-profile has its minimum, $s \approx 0.5$), whereas the one shown by MEGA-'Hazeltine-Meiss MHD' model differs somehow. Growth-rates of MEGA are typically lower than the ones found by HYMAGYC and ORB5 (which are in reasonable agreement among them), and a more detailed analysis to understand such less favorable results are required. Weakly driven modes (with lower n_{H0}/n_{i0} w.r.t. the nominal value) are also observed by HYMAGYC and MEGA-'Standard MHD' model, located within the toroidal gap, where the throat corresponding to $q(s) = 2.5$ occurs, as already observed by HYMAGYC for the peaked off-axis EP density profile case.
Results of runs extending to the non-linear, saturation regime will also be shown, in order to benchmark these codes also in regimes where the EP transport can become relevant.

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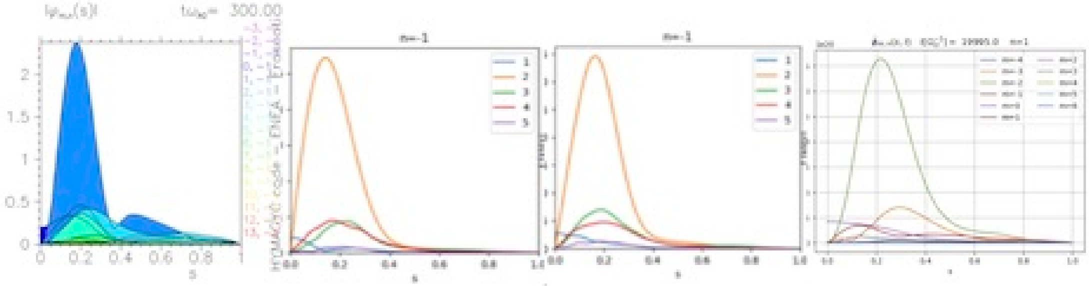

Figure 1: Radial profile of the poloidal components of the eigenfuncion, as obtained for the peaked off-axis EP density profile case, by (starting from left) HYMAGYC, MEGA-'Standard MHD', MEGA-'Hazeltine-Meiss MHD', ORB5.

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