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Turbulence driven magnetic islands in high-β plasmas: generation and non-linear dynamics

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The dynamics of magnetic islands and the role they play in fusion plasmas are usually approached and predicted using extensions of the original theory by Rutherford [1, 2], on which estimates for their impact on the operation of present and future magnetic confinement devices are based. Likewise, diagnostics to detect their presence [3] and techniques to limit their impact are operated on the assumption that the fundamental physics of the phenomenon have been clarified. Still, there are experimentally reported examples of magnetic islands showing up in systems that are predicted to be stable against the formation of such structures [4], which indicates otherwise. The work presented here shows how turbulence that develops in the non-linear phase of a high-β system unstable to interchange modes is capable of generating magnetic islands [5, 6] in all conditions explored numerically, and how the dynamics of these turbulence driven magnetic islands (TDMIs) depend on the interaction with the zonal fields. In particular, competition is found to occur between the zonal flow and the magnetic island when it comes to the repartition the free energy of the system, and the growth of the magnetic island and of the zonal current are found to be tightly inter-dependent. Zonal flows and TDMIs can coexist in a stable manner throughout the simulation. The zonal flow is localized on the resonant surface, which is inside the separatrix of the TDMI, where it can maintain the pressure profile relatively stable, and the magnetic island grows on either side of the resonance, depending on geometry and other factors, where it flattens the pressure profile. From an experimental point of view, the effect of the zonal flow hides the presence of the magnetic island until it has reached a width as much as 4 times the critical width identified by Fitzpatrick [7]. These dynamics are studied by running non-linear simulations using a 6-field reduced electromagnetic fluid model [8] varying β and the magnetic shear, as well as the dissipations for the zonal flow. An analytical approach to the problem is also presented to highlight certain fundamental features of the interplay among the large scale structures and turbulence, in particular the fundamental difference in the magnetic and electric fields due to the former being divergence-free.

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