Instabilities and mixing in a quisi-2D MHD-driven Kolmogorov flow

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ABSTRACT

We use fully resolved direct numerical simulations to study the mixing properties of a quisi-2D MHD-driven Kolmogorov flow with linear drag. Our simulations represent an experimental setup with two thin immiscible liquid layers above magnetic strips of alternating polarity. The bottom non-conducting liquid layer serves as a libricant. The top conducting layer is driven by a steady uniform current. Going beyond linear stability analyses [1,2] we show that the increase in the spatiotemporal complexity of the flow with the driving (controlled by the applied current) is associated with a sequence of bifurcations giving rise to nontrivial equilibrium, periodic, and relative periodic solutions (also known as coherent structures) similar to those found in experiments [3]. Similar types of solutions also arise in the transition from laminar to turbulent flows in plane Couette [4] and pipe Poiseuille flows [5]. In order to find these nontrivial solutions a custom implementation of matrix-free Krylov-subspace Newton solver was developed which uses a modified Arnoldi iteration method suitable for systems with near-continuous spectra. The mixing properties of quasi-2D Kolmogorov flow were previously studied only for time-periodic driving [6]. For steady driving we find the mixing to be strongly correlated with the spatiotemporal complexity of the flow. The mixing properties of the flow change in a discontinuous and non-monotonic manner with increasing Reynolds number. We find that these changes are associated with the rearrangement of the network of separatrices characterizing different steady and time-dependent solutions which serve as transport barriers.

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