Magnetic island coalescence problem in the presence of in-plane shear flow

Jagannath Mahapatra[1,2], Rajaraman Ganesh[1,2], Arkaprava Bokshi[1], and Abhijit Sen[1,2]
[1]Institute for Plasma Research, Gandhinagar, Gujarat-382 428, India,
[2]Homi Bhabha National Institute, Mumbai, Maharashtra-400 094, India
e-mail (speaker): jagannath.mahapatra@ipr.res.in, jaga.physics94@gmail.com

Plasma bulk flows are common in fusion plasma experiments as well as in astrophysical environments and can affect Magnetic reconnection(MR) in many important ways. It is well known that the local, thin current sheets in the plasma are the site of Magnetic reconnection. Therefore, plasma flows around these local current sheets can alter the upstream and downstream flow patterns, hence the reconnection rate. Additionally, the super-Alfvénic shear flows can potentially destabilize the Kelvin-Helmholtz instability (KHI), to couple with reconnection driven MHD instabilities [2]. In the resistive MHD model, the in-plane super-Alfvénic shear flow suppresses the tearing mode instability (TMI) in a thin current sheet [3], hence prevents the magnetic reconnection process and magnetic island formation. However, the effect of shear flow on the system which has preformed magnetic islands [4] has not been studied in detail. Study of the magnetic island coalescence problem in presence of sub- and super-Alfvénic shear flow will help to understand the shear flow effects on the island coalescence or reconnection rate and the role of KHI on the stability of current filaments which are commonly observed in solar and magnetospheric environments.

Using a 2D viscoresistive Reduced-MHD (VR-RMHD) model, we investigate the effect of in-plane shear flow on the magnetic island coalescence problem [1]. We use the BOUT++ framework to solve the model equations numerically on a Cartesian grid. To start the simulation, we use Fadeev's equilibrium [4] as the initial current density profile and a tan-hyperbolic initial shear flow profile. Four different velocity shear length scales (a_v) in comparison to magnetic island width (a_I) with shear flow amplitude (v_0) ranging from sub-Alfvénic to super-Alfvénic values are considered to understand the effect of shear flows on the coalescence instability and its nonlinear fate. When the initial current density profile is perturbed, the current filaments attract each other, forming a thin current sheet at the X-point lying in-between them. This current sheet acts as the site of MR. We measure the reconnection rate as the reconnecting electric field at the X-point. For our presently used domain size, the KHI is stable for $a_v > a_I$. Hence for this a_v value, super-Alfvénic shear flows are unable to disturb the magnetic islands, but the reconnection rate decreases monotonically as v_0 increases (Fig. 1). For $a_v \leq a_I$, the KHI is unstable for super-Alfvénic shear flows and destabilizes the magnetic islands. For all the shear flow parameters considered, we observe the coalescence of magnetic islands by suppressing the KHI. We notice vortices concentric with the magnetic islands. The plasma circulation induces a secondary shear flow on the both sides of reconnecting current sheet which is responsible for reducing the upstream flow and hence the reconnection rate. Moreover, the plasma circulation inside the islands is responsible to stabilize them against the nonlinear KHI. It would be interesting to the study the role of out-of-plane flows on the 2D and 3D island coalescence instability. Also, it is envisaged that the kinetic effects [5] would play important role in shear flow dynamics of magnetic island coalescence.

References:
1. J. Mahapatra, A. Bokshi, R. Ganesh, and A. Sen, Phys. Plasmas **28**, 072103 (2021).
2. L. Chacón, D. A. Knoll, and J. M. Finn, Phys. Lett. A **308**, 187 (2003).
3. P. A. Cassak, Phys. Plasmas **18**, 072106 (2011).
4. V. M. Fadeev, I. F. Kvartskava, and N. N. Komarov, Nucl. Fusion **5**, 202 (1965).
5. J. Mahapatra, J. Chowdhury, R. Ganesh, and L. Villard, Phys. Plasmas **27**, 052509 (2020).

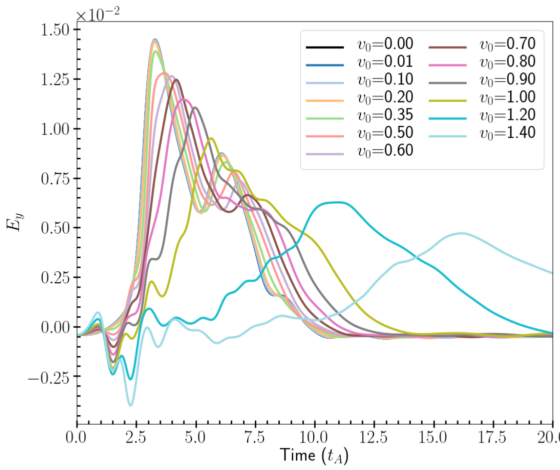

Figure 1: Reconnection electric field E_y as a function of time for $a_v = 2a_I$ with different values of shear flow amplitude v_0.