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# On the Magnetic Reconnection Rates of Resistive Tearing Mode with Dynamic Turbulent Flow Effects

Ahmad Ali,[1] Jiquan Li[1] and Yasuaki Kishimoto[1,2]

[1] *Graduate School of Energy Science, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan*
[2] *Institute of Advanced Energy, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan*

The preexisting turbulence in astrophysical environments can significantly modify the magnetic reconnection process. In this work, we present simulation studies on the effects of dynamic turbulent flows on resistive magnetic reconnection based on two dimensional (2D) reduced resistive MHD model. It is found that the turbulent flow induces a two phase reconnection process: a slowly evolving current sheet is observed after the Rutherford regime, followed by a plasmoid dominated impulsive enhanced reconnection phase, where multiple plasmoids are continuously generated and ejected from the current sheet. The onset, scaling and dynamics of the plasmoid instability are influenced by the frequency, amplitude and radial parity of the turbulent flows.

## 1. Introduction

In many astrophysical environments, the Lundquist number *S*, may easily of the order of $10^{16}$. The corresponding Sweet Parker [1, 2] reconnection rates are much slower than the observed astrophysical reconnection rates. Thus the main challenge of the present day reconnection research is to identify the mechanism responsible for the observed fast reconnection rate. Small-scale turbulence is one of the possible candidates to trigger the fast reconnection and hence fill the gap between theory and observations.

The pioneering numerical study of magnetic reconnection in the presence of turbulence was performed by Matthaeus & Lamkin [3] within the 2D simulation model and concluded that the formation of the X-points can produce faster reconnection. The first detailed analytical model of turbulent reconnection was developed by Lazarian and Vishniac [4], where they suggested that multiple reconnection sites along the current sheet, give rise to higher reconnection rates. In 2D simulations, the enhancement of reconnection rates in the presence of background turbulence or white noise has been confirmed [5-7]. The overall conclusion of these studies is that multiple plasmoids lead to faster reconnection rates. Instead of applying the external turbulence forcing in the form of random noise, it may be interesting to consider a finite frequency small-scale turbulent flow, similar to ion temperature gradient (ITG) driven turbulence in the MHD tearing mode[8]. Actually, the coexistence of MHD activities including the tearing mode and ITG driven drift wave have been reported to occur commonly in fusion plasmas [9,10]. In this study, we model a finite frequency ITG type flow in the framework of reduced MHD system and investigate the effects of such flow on the reconnection behavior of resistive tearing mode.

## 2. Physical Model

Our simulation results are based on numerical simulations of the 2D incompressible reduced MHD equations in the (x, y) plane, which can be written in the normalized form as follows,

$$\partial_t \psi = -[\phi, \psi] + \eta \nabla^2 (\psi - \psi_0)\,, \qquad (1)$$

$$\partial_t (\nabla^2 \phi) = -[\phi, \nabla^2 \phi] + [\psi, \nabla^2 \psi] + \mu \nabla^2 (\nabla^2 \phi). \qquad (2)$$

Where $\psi$ is the flux function so that the magnetic field is represented as $\mathbf{B} = B_{0z}\boldsymbol{e_z} + \boldsymbol{e_z} \times \boldsymbol{\nabla}\psi$ and $\phi$ is the stream function so that velocity field is represented as $\mathbf{v} = \boldsymbol{e_z} \times \boldsymbol{\nabla}\phi$ . The equilibrium magnetic flux is given by $\psi_0\,(x) = 1/\cosh^2(x)$. The background turbulent flow is represented as follows [8],

$$\phi^{ITG}\left(t, x, k_y^{ITG}\right) = A_{ITG}\hat{\phi}^{(n)}(x) e^{-i\Omega t + i k_y^{ITG} y}, \quad (3)$$

where, $A_{ITG}$ is the constant amplitude of the flow and $\hat{\phi}^{(n)}$ represents the radial eigen-function corresponding to the eigenvalue $\Omega$ .The eigen-function is expressed by the n-th Hermite function which decides the parity of turbulent flow. The main purpose of this study is to analyze the behavior of effective reconnection rate $\bar{E}$ in the nonlinear growth phase of the tearing mode in parameter space $\bar{E}(\eta, \mu, parity, \Omega, A_{ITG})$.

## 3. Onset of the Impulsive Bursty Reconnection

This work is planned to investigate the effects of background turbulent flow on nonlinear evolution of resistive tearing mode. Simulations with the

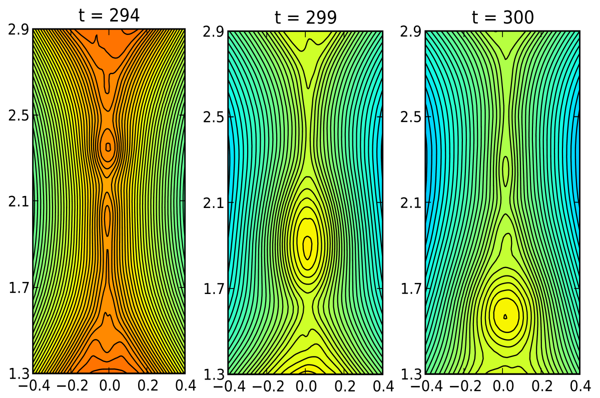


Fig.1: Flux contours for nonlinear simulation run with $\eta = 2.8 \times 10^{-4}$ , $\Delta' = 17.3$ , $A_{ITG} = 8 \times 10^{-4}$ and frequency $\Omega = 0.36$. Monster plasmoid is formed as the tiny plasmoids coellease with each other.

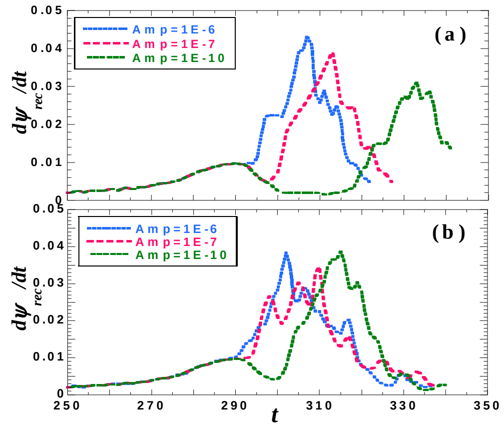


Fig. 3: Time history of the reconnection rate is plotted for turbulent flow with (a) even radial parity flow and (b) odd radial parity flow; for three different amplitude cases with the same frequency $\Omega = 0.08$.

turbulent flow reveal that the single secondary island generated in the current sheet of the laminar case, is replaced by multiple dynamic plasmoids as shown in Fig. 1. In the beginning, the plasmoid coalesces with the neighboring plasmoid, resulting in a monster plasmoid, which eventually merges with the primary island.

Specifically, the magnetic reconnection of the resistive tearing mode proceeds in two phases: in the first phase, the X-point configuration collapses to a narrow current sheet which evolves slowly. In the second phase, plasmoid instability is triggered, where multiple plasmoids are continuously generated and ejected from the current sheet. The plasmoid instability leads to an abrupt increase in the reconnection rate, which is usually measured as the change rate of the reconnected magnetic flux along the current sheet at $x = 0$, as depicted in Fig. 2. Note that the reconnected flux is the difference between the maxima and minima of the magnetic flux along the current sheet.

Next, we examine the dependence of reconnection rates on the flow amplitude, both for even and odd radial parities. Simulation results for three amplitudes of the turbulent flow are plotted in Fig. 3. Note that the two phase reconnection is more evident for the low amplitudes of the flow. In the case of even parity, the peak reconnection rate moderately decreases with the decreasing flow amplitude. However, for the odd parity flow, the peak reconnection rate is almost independent of the flow amplitudes. More importantly, the onset of fast reconnection phase is delayed with the decreasing amplitude of the turbulent flow. The reconnection rate dependence on other flow parameters, such as frequency and wave number will be reported in the presentation.

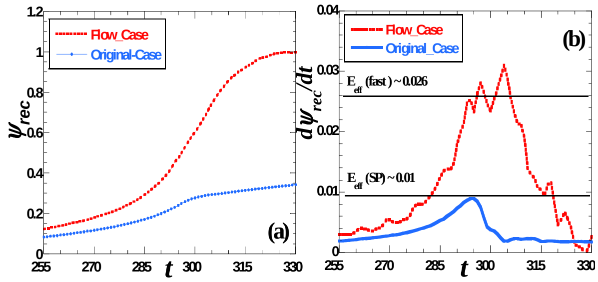


Fig. 2: Reconnected flux (a) and the corresponding reconnection rates (b) for the same run as in Fig. 1 are compared with the original laminar case.

## 4. Conclusions

In this study, the effects of a time dependent turbulent flow on the reconnection rates of resistive tearing mode are investigated using reduced MHD equations. It is found that in the presence of turbulent flow a fast impulsive type reconnection occurs after the slowly evolving current sheet. The onset and dynamics of the fast reconnection phase is found to depend on the flow amplitude and parity.

## References


[1] P. A. Sweet, in *Proceedings of the IAU Symposium 6: Electromagnetic Phenomena in Cosmical Physics*, (Cambridge University Press, Cambridge, England, 1958) p. 123.

[2] E. N. Parker, J. Geophys. Res. **62** (1957) 509.

[3] W. H. Matthaeus and S. L. Lamkin, Phys. Fluids, **29**, (1986) 2513.

[4] A. Lazarian and E. T. Vishniac, ApJ, **517** (1999) 700.

[5] N. F. Loureiro, et al., Mon. Not. R. Astron. Soc. **399** (2009), L146-L150.

[6] Y. Huang, and A. Bhattacharjee, Phys. Plasmas, **17** (2010) 062104.

[7] M. Skender and G. Lapenta Phys. Plasmas, **17** (2010) 022905.

[8] Jiquan Li *et al.*, Phys. Plasmas, **19** (2012) 030705.

[9] F. Militello *et al.*, Phys. Plasmas, **15** (2008) 050701.

[10]Jiquan Li *et al.*, Nucl. Fusion, **49** (2009) 095007.