Final Report on contract NAGW-3449 entitled

"Cross-field Current Instability for Substorm Expansions"

The funding provided by the above-referenced NASA grant has enabled us

(1) to investigate the quasi-linear evolution of the IWI [Lui et al., 1993] and that of the generalized MTSI/IWI [Yoon and Lui, 1993],

(2) to carry out the linear analysis of the LHDI to elucidate the difference between it and the MTSI/IWI instability [Yoon et al., 1994],

(3) to conduct some preliminary nonlocal analyses of the MTSI [Lui et al., 1995] and the IWI [Yoon and Lui, 1996] modes,

(4) to study low-frequency shear-driven instability and its nonlinear evolution, which might compete with the CCI [Yoon et al., 1996], and

(5) to study the evolution of current sheet during late substorm growth phase by means of 2-D Hall-MHD simulation in order to obtain a better understanding of the current sheet equilibrium crucial for CCI theory [Yoon and Lui, 1997]

We elaborate these accomplishments in the following paragraphs:

(1)   We have investigated the quasi-linear evolution of the IWI in the Earth's magnetotail environment by employing the techniques developed earlier by Yoon [1991] but extending it to include a finite electron drift [Lui et al., 1993]. For mathematical simplicity, we considered only the wave mode with propagation parallel to the magnetic field. The basic assumption in the analysis is that the ions are unmagnetized and streaming across the tail (in the dawn to dusk direction) perpendicular to the ambient magnetic field which is pointed northward. The electrons are treated as fully magnetized and it is assumed that they remain stationary initially. The analysis allows both species to possess finite cross-field drifts as time evolves. The waves propagate in the northward direction along the ambient magnetic field. Both the electrons and the ions are assumed to be isotropic initially, but they are allowed to develop anisotropy in the quasi-linear regime. The unmagnetized ion population is described by a drifting Maxwellian distribution but the exact shape of the velocity distribution is not crucial since the instability is a reactive type and is not attributed to microscopic wave-particle resonance interactions.

The quasi-linear calculation shows that the saturation level is achieved when the ion drift speed relative to the electrons is reduced by about 15-28% and the ion temperature along the field line is enhanced by ~25-90%. The amount of

current reduction is quite consistent with observations [Lui, 1978; Jacquey et al., 1991]. From this result, we have provided an estimate on the anomalous resistivity based on the rate of reduction of the ion drift speed and have found it to have values 11 to 12 orders of magnitude over the classical resistivity due to Coulomb collisions. Furthermore, we have noted that current reduction as a result of the nonlinear development of CCI should lead to a force imbalance which would inject plasma typically earthward. This finding provides a means to couple the nonlinear development of CCI to large-scale dynamics and to account for the well-known phenomenon of substorm injection observed by geosynchronous and other satellites in the near-Earth plasma sheet.

As a follow up of the above study, we have conducted a quasi-linear analysis of the generalized treatment of both IWI and MTSI and have demonstrated that these two modes lie on the same dispersion surface [Yoon and Lui, 1993]. This more general study has verified also the previous study which treated only the IWI mode.

(2)   We have conducted the linear analysis of the LHDI in a high plasma beta regime, incorporating fully the electromagnetic effects from both electrons and ions as well as plasma and field gradients of a current sheet [Yoon et al., 1994]. In this study, we show the basic difference on the formulation of this mode from the MTSI and IWI modes. We have also provided corrections to some inconsistencies found in some earlier work in the literature on these modes. The work has improved our fundamental understanding of these modes. It also forms an important foundation for nonlocal analysis of CCI.

(3)   We have begun a close look at the nonlocal character of CCI [Lui et. al., 1995; Yoon and Lui, 1996]. We have adopted several simplifying assumptions in our first approach. We have examined first the MTSI in which only electrostatic perturbations were considered. As a further simplification, we have neglected thermal and kinetic effects by taking the cold fluid approximation. In spite of these simplifying assumptions, we have gained additional insights on the onset threshold of CCI. The result demonstrates that nonlocal analysis yields a more stable system than is suggested by the local theory. Furthermore, a current sheet with a constant velocity associated with the current (exemplified by the Harris equilibrium current sheet) is stable with respect to the nonlocal MTSI, whereas one with a prominent velocity peak at its center is unstable when it is sufficiently thin. This indicates that the onset threshold is sensitive to the global characteristics of the current sheet and the precise onset threshold can be determined only through nonlocal analysis. Therefore, a thin current sheet with a small velocity shear can be stable, thus accounting for observations which reveal that a thin current sheet can remain stable for extended period before the occurrence of current disruption [Sergeev et al., 1993; Mitchell, 1994]. We

have also carried out a nonlocal analysis of the IWI which gives similar results as that for the nonlocal study of MTSI.

(4)   Our nonlocal analyses which invokes a substantial velocity shear in the current sheet have prompted us to investigate the velocity-shear driven MHD instability (i.e., Kelvin-Helmholtz instability or KHI). As a first step, we have focused solely on the linear and nonlinear development of KHI, under the same current sheet equilibrium configuration as we have used in nonlocal CCI analysis. Indeed, we have found that for sufficiently sheared current sheet, KHI may indeed be another mechanism that can contribute to the current disruption process [Yoon et al., 1996]. Detailed interplay between CCI and KHI must be investigated further, however.

(5)   We have begun to investigate several crucial aspects in the modeling of equilibrium current sheet configuration which forms the starting point of CCI analyses. One of them is the construction of exact 2D and 3D magnetotail equilibrium model. We have succeeded in the derivation of analytically exact 2D equilibrium magnetic tail solution from the first principle [Yoon and Lui, 1997]. An important issue is whether the equilibrium model adopted in the CCI analysis is justified, in which the ions are assumed to carry the major fraction of the cross-tail current. Using the exact equilibrium model, we have carried out Hall-MHD simulation of late substorm growth phase. Although Hall-MHD does not have the field-aligned electron dynamics, because it is a two-fluid mode, we were able to demonstrate that in the late growth phase, the near-Earth tail region is indeed characterized by ions dominating the cross-tail current [Yoon and Lui, 1997]. Therefore, the starting point of CCI analysis which corresponds to late growth phase of substorm is justifiable.

References (* represents work supported by the grant)

Jacquey et al., *Geophys. Res. Lett.*, *18*, 389, 1991.
Lui, *Geophys. Res., Lett.* ,*5*, 853, 1978.
*Lui, *J. Geophys. Res.*, *101*, 13067, 1996.
Lui et al., *J. Geophys. Res.*, *98*, 153, 1993.
*Lui et al., *J. Geophys. Res.*, *100*, 19147, 1995.
Mitchell, *Proceedings of ICS-2*, 105, 1994.
Sergeev et al., *J. Geophys. Res.*, *98*, 17345, 1993.
Yoon, *Phys. Fluids, B, 3*, 3074, 1991.
Yoon and Lui, *Phys. Fluids, B, 5*, 836, 1993.
*Yoon and Lui, *J. Geophys. Res.*, *101*, 4899, 1996.
*Yoon and Lui, Two-dimensional Hall-MHD simulation of current sheet dynamics during substorm growth phase, *J. Geophys. Res.*, submitted, 1997.
*Yoon et al., *Phys. Plasmas, 1 (9)*, 3033, 1994.
*Yoon et al., *J. Geophys. Res.*, *101*, 27327, 1996.