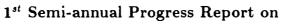**1st Semi-annual Progress Report on**

NASA Grant NAGW-1483 (6/1/93 - 5/31/94)

PHYSICS OF MAGNETOSPHERIC BOUNDARY LAYERS

Period: **6/1/93 - 11/31/93**

Principal Investigator: I.H. Cairns (University of Iowa)

Date submitted: 20 December 1993.

1   Introduction

NASA grant NAGW-1483 started as a Space Physics Theory Program Grant in December 1990 under the direction of Professor Chris Goertz. Following 1991's multiple murders, the grant passed into the stewardship of Dr. John Lyons and, more recently, Dr. Iver Cairns. During the last six months Dr.'s Cairns, Paul Hansen, Barry Harrold, Lyon, Ebraahim Moghaddam-Taaheri, and Ken-ichi Nishikawa, together with Mr. Bob Holdaway, have been working actively under the aegis of the grant. Only Dr.'s Hansen, Harrold and Moghaddam-Taaheri, and Mr. Holdaway are supported by the grant.

The central ideas of this grant are that (1) the magnetospheric boundary layers link disparate regions of the magnetosphere together, and (2) the global behaviour of the magnetosphere can be understood only by understanding the linking mechanisms. Accordingly the present grant includes simultaneous research on the global, meso-, and micro-scale physics of the magnetosphere and its boundary layers. These boundary layers include the bow shock, magnetosheath, the plasma sheet boundary layer, and the ionosphere. Analytic, numerical and simulation projects have been performed on these subjects, as well as comparison of theoretical results with observational data. Very good progress has been made, with 4 papers published or in press and 2 additional papers submitted for publication during the six month period 1 June - 31 November 1993. At least 2 projects are currently being written up. In addition, members of the Group have given papers at scientific meetings. The further structure of this report is as follows: Section 2 contains brief accounts of research completed during the last six months, while Section 3 describes the research projects intended for the grant's final period.

2   Progress made in the period June - November 1993

2.1   Global &Bow Shock Work

Dr.'s Cairns and Lyon have been using Dr. Lyon's global, 3-D, ideal MHD simulation code to study changes in the standoff distance and shape of Earth's bow shock due to variations in the Alfven Mach number, magnetic field orientation, and ram pressure of the solar wind. Comparisons are made with the gasdynamic theory proposed by John Spreiter and colleagues and recent observations of unusually distant bowshocks at Venus and Earth at low Mach numbers $\gtrsim 1$. The simulations show unusually distant bow shocks that are qualitatively consistent with the observations but differ from the gasdynamic results. Research is currently procceding on several aspects of the results.

Dr.'s Cairns and Grabbe have generalized Spreiter's gasdynamic theory to include MHD effects. They have shown that phenomenological replacement of the gasdynamic (sonic) Mach number by the Alfven or the fast magnetosonic Mach number is inappropriate.

Magnetic field orientation effects and plasma beta effects are also shown to be significant. This work has been submitted for publication to Geophysical Research Letters:

- **I.H. Cairns and C.L. Grabbe**, An Analytic MHD Theory for the Standoff Distance of Earth's Bow Shock, *Geophys. Res. Lett.*, submitted, 1993.

Dr. Nishikawa has been working on the new 3-D, electromagnetic PIC simulation code 'Tristan' developed by Dr.'s O. Buneman, T. Neubert and himself. A paper on solar wind-magnetosphere interactions was published in 1992 [Buneman et al., 1992]. This global work has continued, resulting in an invited paper at the recent Aussois conference that was published in the Proceedings. This code is also being used in solar and astrophysical contexts.

- **K.-I. Nishikawa, O. Buneman, and T. Neubert**, Solar Wind-Magnetosphere Interaction as Simulated by a 3-D, EM Particle Code: with a Southward IMF, in *Proceedings of Spatial-Temporal Analysis for Resolving Plasma Turbulence (START)*, ESA WPP-047, 413, 1993.

2.2 Magnetosphere

Dr.'s Hansen and Harrold have applied the MHD equations to the situation of an inhomogeneous plasma with open field lines (that is, no boundary conditions applied at the ends). This situation is intended as a model of the plasma sheet boundary layer near the lobe. They find that the usual Alfven resonance singularity does not occur. Instead, absorption of Alfven wave Poynting flux incident from the lobe occurs over a broad region rather than in an infinitely thin layer. This research will be published as

- **P.J. Hansen and B.G. Harrold**, Parallel Inhomogeneity and the Alfven Resonance 1. Open Field Lines, *J. Geophys. Res.*, in press, 1993.

Dr. Hansen has worked with Dr. J.E. Borovsky on a mechanism that has been proposed for particle energization at substorm onset: a strong inductive electric field breaks adiabatic invariance. This field is due to the time variation of the magnetic field during dipolarization. Detailed analysis of the situation indicates, however, that only weak breaking of adiabatic invariants occurs. This argues against the mechanism contributing significantly to the observed particle injections.

- **J.E. Borovsky and P.J. Hansen**, Can Substorm Dipolarization Break First Adiabatic Invariants?, in preparation, 1993.

Dr.'s Harrold and Hansen have also examined whether so-called 'vortex' waves observed in the magnetotail can be interpreted in terms of eigenmodes of the magnetotail plasma sheet. The analysis uses a 1-D slab model along X with Y and Z gradients, the warm MHD equations, and an adiabatic equation of state. They find that one of the eigenmodes closely matches the phase and amplitude characteristics of the observed vortex modes. A paper presenting these results has been submitted for publication:

- **B.G. Harrold and P.J. Hansen**, Vortex eigen modes of the plasma sheet, *Geophys. Res. Lett.*, submitted, 1993.

Dr. Hansen has also attempted, unsuccessfully, to develop a cellular automata model of substorm dipolarization onset, in the spirit of the discrete models in the field of self-organized criticality. Conversations with Dr. Borovsky, however, indicate that existing data do not show the characteristic signatures of self-organized criticality (such as f^{-1} spectra). This project will not be continued.

Mr. Holdaway continued his work on a mixed PIC-Vlasov simulation of the physics of resonant absorption of Alfven waves. Several computational difficulties have emerged and been difficult to solve. He hopes to complete his Ph.D. thesis in early 1994.

2.3 Microphysics

Dr.'s Harrold and Nishikawa have refurbished the 2 1/2-D PIC code used by Goertz et al. [1991] to investigate solitary ion cyclotron waves (or double layers) generated on auroral field lines in the presence of largescale Alfven waves. The code is now running well. Both electron acceleration and solitary wave structures are observed. The solitary waves propagate along the magnetic field at the electron thermal speed.

Dr. Harrold has used linear Vlasov theory to determine numerically the dispersion relation of low frequency electromagnetic waves in a magnetized plasma. Comparisons with analytic theory have also been performed. Regions of parameter space appropriate to the ionosphere, the plasma sheet, and the lobes have been examined. Topics of interest include whether the firehose and other instabilities are allowed and whether mode conversion into Kinetic Alfven waves is permitted. Dr. Harrold presented these results at the Spring AGU meeting. Extensions and refinements of these analyses are proceeding now.

Dr. Hansen has been pursuing soliton physics in conjunction with Prof. K. Lonngren. He hopes to apply the results to the ion cyclotron solitons/double layers observed in auroral field lines. A paper has been published recently:

- **P.J. Hansen and K.E. Lonngren**, On the Prediction of the Number of Solitons Excited by an Arbitrary Potential: An Observation from Inverse Scattering, *Physica D*, 68, 12, 1993.

Dr. Moghaddam-Taaheri has worked primarily on critical ionization velocity (CIV) physics in the last six months. In CIV an initial seed ionization leads to an ion beam which drives lower hybrid waves, the waves resonantly accelerate electrons, and the electrons then ionize more of the cloud's gas particles in collisions, thereby setting up a feedback loop. Dr. Moghaddam-Taaheri's recent work illuminates the importance to the CIV yield of the gas cloud's finite size and the ambient plasma density:

- **E. Moghaddam-Taaheri, G. Lu, C.K. Goertz, and K.-I. NIshikawa**, Particle-in-cell simulations of the CIV effect in finite size clouds, *J. Geophys. Res.*, in press, 1993.

3 Research Projects for December 1993 - May 1994

The projects that we currently intend to pursue in the next six months, and the associated personnel, are as follows:

1. Global MHD simulations of the bow shock and magnetopause as a function of Alfven Mach number, sonic Mach number, ram pressure, and magnetic field orientation. (Cairns and Lyon.)

2. Analytic investigations into the position and shape of Earth's bow shock. (Cairns, Grabbe, and Hansen.)

3. Investigations of the solar wind-magnetosphere system using the Tristan code. (Nishikawa.)

4. Completing and running the mixed PIC/Vlasov code on resonant Alfven wave absorption. (Holdaway and Hansen.)

5. PIC simulations of the ion cyclotron instability within a propagating Alfven wave using the Goertz et al. [1991] code. (Harrold and Nishikawa.)

6. Inhomogeneity and the Alfven wave resonance. (Hansen and Harrold.)

7. Instabilities and Alfven wave mmode conversion using Vlasov theory. (Harrold.)

8. CIV physics. (Moghaddam-Taaheri, Nishikawa and Cairns.)

4 References

Buneman, O., T. Neubert, and K.-I. Nishikawa, Solar wind - magnetosphere interaction as simulated by a 3-D EM particle code, *IEEE Trans. Plasma Sci.*, 20, 810, 1992.

Goertz, C. K., T. Whelan, and K.-I. Nishikawa, A new numerical code for simulating current-driven instabilities on auroral field lines, *J. Geophys. Res.*, *96*, 9579, 1991.

5   Publications Supported Directly by this Grant

I.H. Cairns and C.L. Grabbe, An Analytic MHD Theory for the Standoff Distance of Earth's Bow Shock, *Geophys. Res. Lett.*, submitted, 1993.

P.J. Hansen and B.G. Harrold, Parallel Inhomogeneity and the Alfven Resonance 1. Open Field Lines, *J. Geophys. Res.*, in press, 1993.

P.J. Hansen and K.E. Lonngren, On the Prediction of the Number of Solitons Excited by an Arbitrary Potential: An Observation from Inverse Scattering, *Physica D*, 68, 12, 1993.

B.G. Harrold and P.J. Hansen, Vortex eigen modes of the plasma sheet, *Geophys. Res. Lett.*, submitted, 1993.

K.-I. Nishikawa, O. Buneman, and T. Neubert, Solar Wind-Magnetosphere Interaction as Simulated by a 3-D, EM Particle Code: with a Southward IMF, in *Proceedins of Spatial-Temporal Analysis for Resolving Plasma Turbulence (START)*, ESA WPP-047, 413, 1993.

E. Moghaddam-Taaheri, G. Lu, C.K. Goertz, and K.-I. NIshikawa, Particle-in-cell simulations of the CIV effect in finite size clouds, *J. Geophys. Res.*, in press, 1993.