N93-18645

RECENT ADVANCES IN MPD THRUSTER RESEARCH AT PRINCETON

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EPPDyL Staff and Research Activities

Research Staff	Position	Research Activities
Robert G. Jahn	Lab. Director	Principal Investigator
Arnold J. Kelly	Lab. Manager	ES sprays & Plasma Propulsion
Waldo Von Jaskowsky	Research Consultant	Plasma Spectroscopy
Edgar Choueiri	Research Associate	Plasma Propulsion, & Space Plasma Physics

Students	Level	Research Activities
Alec Gallimore (currently at the U. of Michigan)	Ph.D.	Anode Power Deposition
Kevin Diamant	Ph.D.	Anode Region Wave Processes
Dennis Tilley	M.S.	Plasma Instabilities in the kW level MPD Thruster
Thomas Randolph	M.S.	Thruster Ionization Processes
Jeffrey Fillmore	M.S.	Lithiated Cathode Plasma Thruster Research
Giuliano Caldo	M.S.	Plasma Thruster Numerical Modelling
Scott Wunsch	B.S.	Coordinate Transformations for Plasma Thruster Numerical Modelling
Tim Kniker and Robert Braugner	B.S.	MPD Thruster Performance Measurements using the EPPDyL Thrust Stand
Brian Kantsiper	B.S.	Modelling of Critical Ionization Velocity (CIV) Experiments in Space
John Kline	B.S.	Computer Control of the MPD Thruster Testing and Diagnostics Facility at EPPDyL

Summary of Last Year's Findings

ANODE:
(Gallimore)

* Anode losses are **dominant** at power levels between 2 kW and 30 kW, **Important** between 30 kW and 200 kW and an **Engineering Challenge** above 200 kW.

* Anode fall and hence anode power fraction scale with the electron Hall parameter, Ω_e.

PLASMA:
(Choueiri, Tilley)

* The existence of current-driven micro-instabilities **(LHCDI)** has been established theoretically and experimentally and was found to be largely **independent** of power level for similar devices operating at the same ξ . ($\xi^2 \sim J^2/\dot{m}$).

* It was speculated that these micro-instabilities might play an important role in **frozen flow** and **anode** losses.

CATHODE:
(Polk, Chamberlain)

* **Evaporation** is the dominant mechanism for cathode erosion.

* **Low work-function** cathode can decrease the cathode erosion rate by orders of magnitude.

Summary of this Year's Activities & Findings

(Details and supporting data are on the following viewgraphs)

* **The scaling of anomalous resistivity with the Hall parameter.**
(Choueiri)

* **The relation between anomalous resistivity and the anode drop.**
(Gallimore, Diamant)

* **The presence of micro-turbulence in the anode region.**
(Diamant)

* **Numerical simulations with anomalous transport.**
(Caldo, Wunsch, Choueiri)

* **The use of magnets to reduce anode dissipation.**
(Gallimore)

* **Performance testing with the new anode.**
(Kniker, Braugner)

* **The mechanisms behind the ionization sink.**
(Randolph, Kantsiper, Choueiri)

* **Lithiated cathode research.**
(Fillmore)

Previous and Current Understanding

The energy invested in ionization and the anode region dissipation (especially at low power) seem to be the most important causes of inefficiency for the MPD thruster. Consequently we have an on-going research program for each of these two problems.

Last year

Existence of Microinstabilities: Last year we only had speculations on the nature of the dissipative mechanisms controlling the importance of these two sinks. There was theoretical evidence from *Choueiri* on the presence and importance of LHCDI in the MPD thruster plasma as well as experimental support for the existence and resilience of such microinstabilities from *Tilley* and *Choueiri* for both kW and MW level devices.

The scaling of Va with the Hall parameter : *Gallimore* undertook extensive measurements of the anode drop and re-established the strong dependence of the anode drop on the electron Hall parameter. No solid link existed at that time between the anode drop and the role of microinstabilities.

Recent developments

The scaling of anomalous resistivity with the Hall parameter: Since then, *Choueiri* added many real effects to his model of microinstabilities and carried the theory into the nonlinear phase to study the impact of such instabilities on the basic transport processes in the plasma through the induced microturbulence. One of the major findings of that study is the strong dependence of the anomalous resistivity on the electron Hall parameter. This led to the speculation that the anode drop may be due to the turbulence-induced anomalous resistivity.

The relation between anomalous resistivity and the anode drop: Shortly thereafter, *Diamant* and to a larger extent *Gallimore* inferred the local resistivity near the anode from experimental measurements and found it to be up to an order of magnitude larger than the classical value. This has considerably strengthened the link between the anode drop and plasma turbulence.

The presence of turbulence in the anode region: To further investigate this possible link, *Diamant* has undertaken a systematic probing of the plasma very near the anode looking for evidence of microturbulence. His results were positive. Prominent peaks in the fluctuating energy spectra are at and very near the frequencies (lower hybrid frequency) predicted by the wave stability and microturbulence theories. We are now relatively more confident of our earlier speculations concerning the role of microturbulence in the dissipation.

Numerical simulation with anomalous transport: In order to study the role of the above phenomena and relate them to the global flow problem *Caldo* used the anomalous transport models developed by *Choueiri* in a state-of-the-art two-D, two-fluid code to investigate *self-consistently* the effects of the turbulence on the flow and vice-versa. He found that the plasma regions near the cathode's tip and root and near the anode tip are critical from the point of view of anomalous transport.

Wunsch has developed a coordinate transformation algorithm that allows the adaptation of the MPD flow code to any axi-symetric geometry. *Choueiri* has implemented specialized compilers for the MPD code on the Cornell supercomputer that allow an order of magnitude speed up in the execution performance over that previously attainable on that machine.

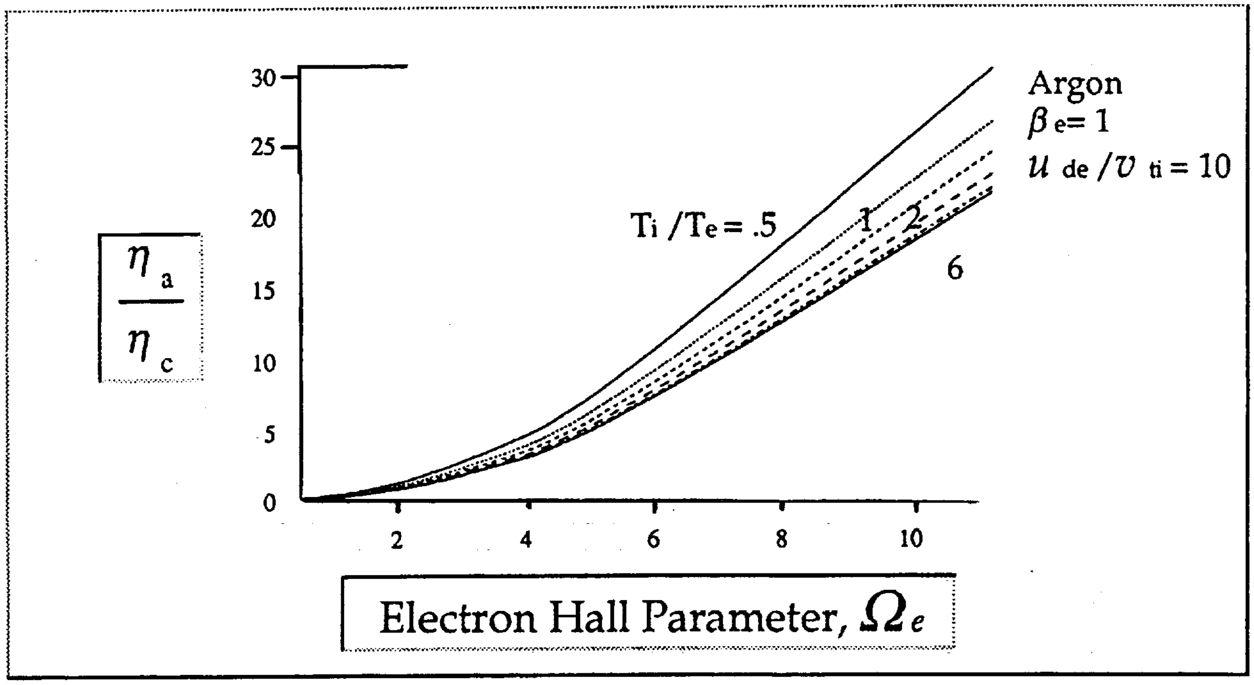
The use of magnets to decrease dissipation: Spurred by the strong scaling of the anode drop with the electron Hall parameter, *Gallimore* implanted a series of small permanent magnets in the anode that were designed to effectively annul the local magnetic field in the anode region thus hopefully decreasing the resistivity and dissipation. While the anode drop seems to have been sensibly decreased the total voltage seemed little effected.

Performance testing with the new anode: In order to follow up on the possibility of performance improvement with the magnetically annuled anode, *Kniker* and *Braugner* have just finished a relative efficiency comparison of the new and old anodes using the laboratory's thrust stand. Their experiments showed that, unfortunately, the new anode does not offer a higher thrust efficiency than the older one.

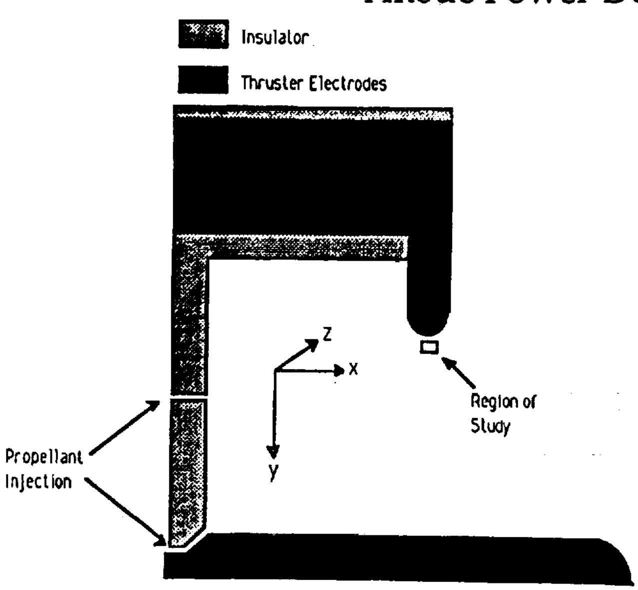
The mechanisms behind the ionization sink: The link between plasma microturbulence and excessive ionization is today as speculative as was the link between microturbulence and the anode drop last year. It is speculated from theory that electrons should benefit from the preferential heating of the unstable waves and cause a very efficient ionization through the CIV effect thus tying up a substantial fraction of unrecoverable energy in singly, doubly and triply ionized atoms. Such anomalous ionization would typically happen abruptly through spatially well defined ionization fronts. The existence of such fronts has not been properly established. *Randolph* has set out to investigate spectroscopically whether such fronts do actually exist inside the chamber of the MPD thruster. He found that a rapid ionization region possibly exists upstream of his physical viewing window and has recently succeeded in pushing this region within that window by advancing the discharge forward through the use of a partly insulated cathode.

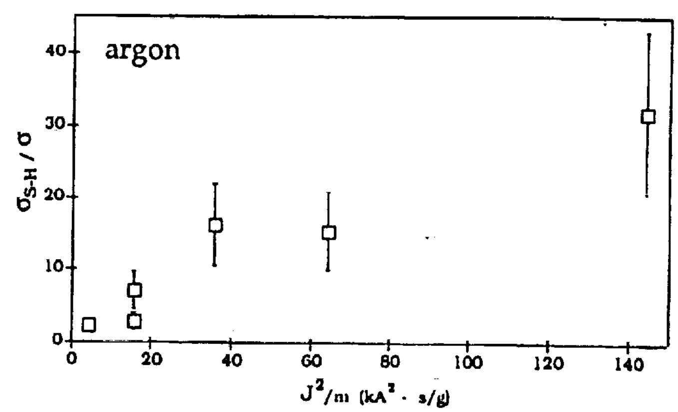
Another program aimed at the study of the fundamental aspect of the CIV effect was initiated recently. Experiments staging a CIV interaction through the injection of a neutral gas from the Russian APEX satellite have been undertaken recently and are currently being analyzed by *Choueiri*. He is currently planning more optimized gas release experiments on APEX during the upcoming months using among other tools, a kinetic stability model for CIV interactions developed at EPPDyL by *Kantsiper*.

Lithiated cathode research: *Fillmore* has finished the calibration and the preparation for his upcoming experiments on the use of a lithiated cathode for the control of cathode erosion rates. Lithiated cathodes are expected to yield orders of magnitude reduction in the erosion rate, thus eventually relegating the cathode erosion problem to the arena of development engineering as an essentially resolved fundamental problem.



Anode Power Deposition in MPD Thrusters





Inferred Electrical Conductivity

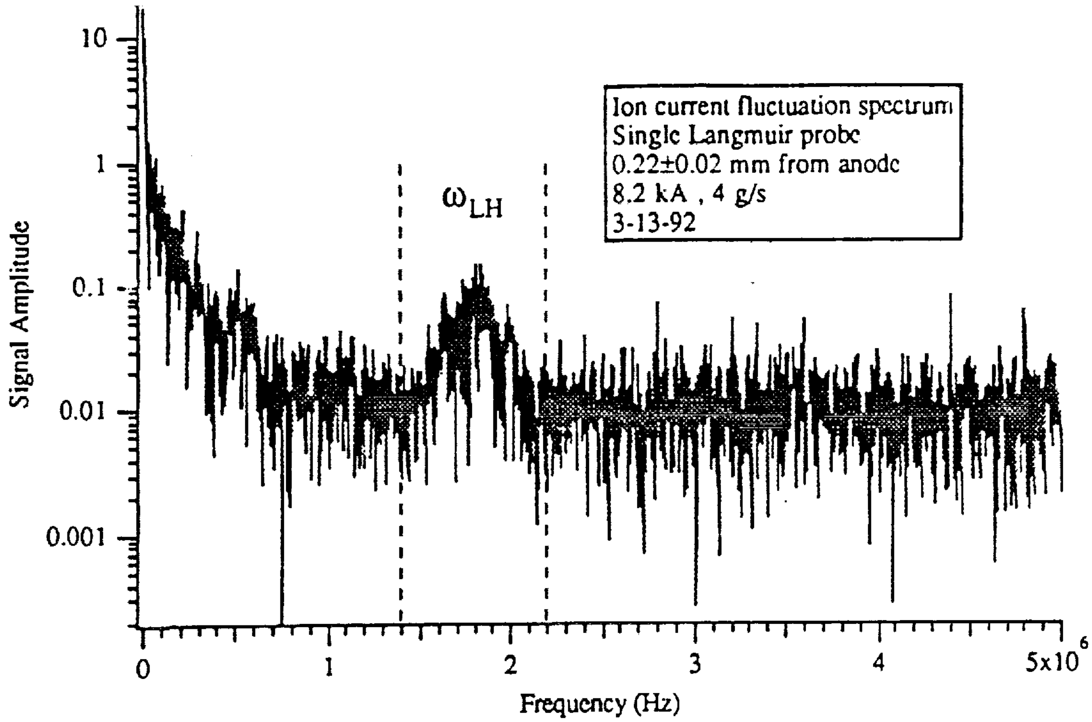


Figure 1. Spectrum recorded 0.22 mm from anode at 8.2 kA, 4 g/s.

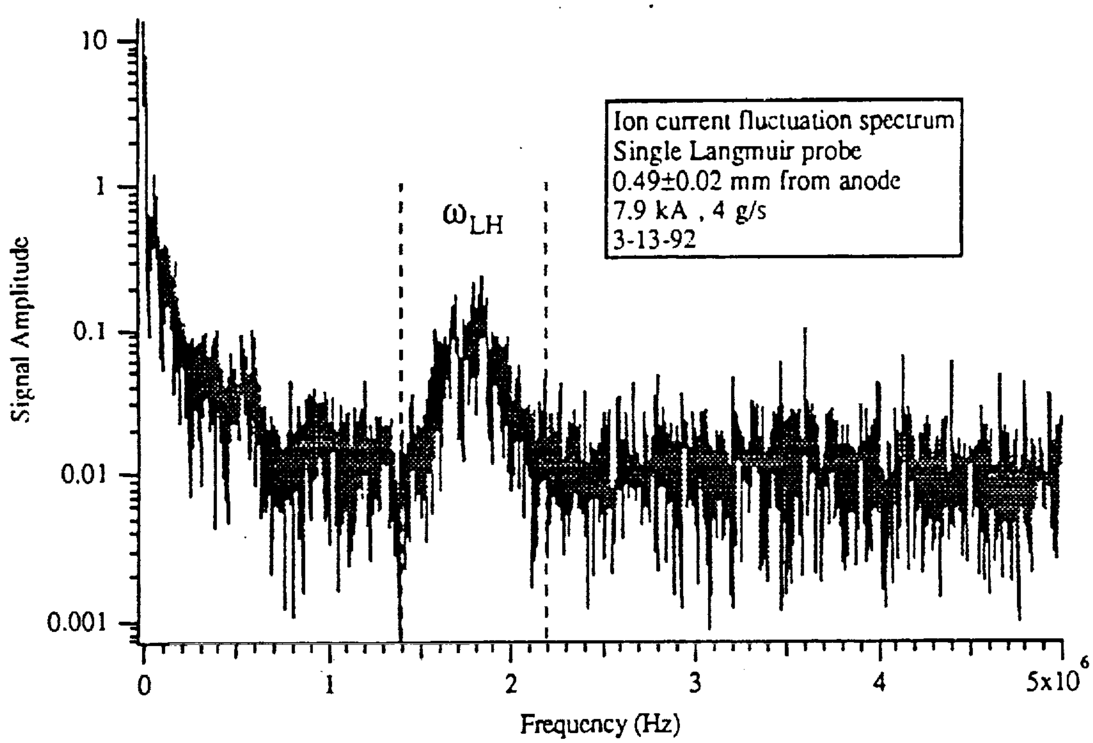


Figure 2. Spectrum recorded 0.49 mm from anode at 7.9 kA, 4 g/s.

Evidence of Lower Hybrid Turbulence Near Anode

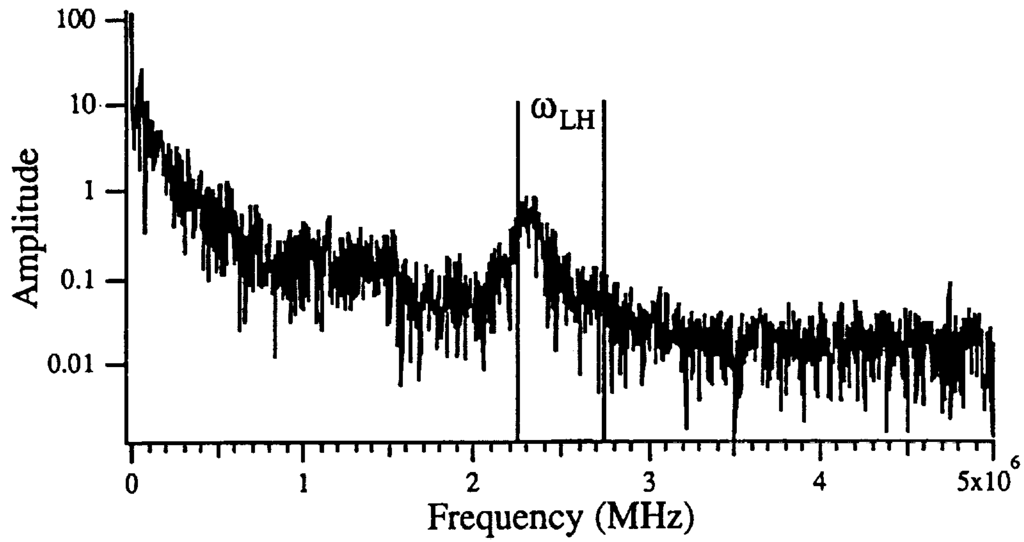


Fig. 1. Spectrum of ion saturation current fluctuations 1 mm from anode lip. From operation at 17 kA, 16 g/s argon.

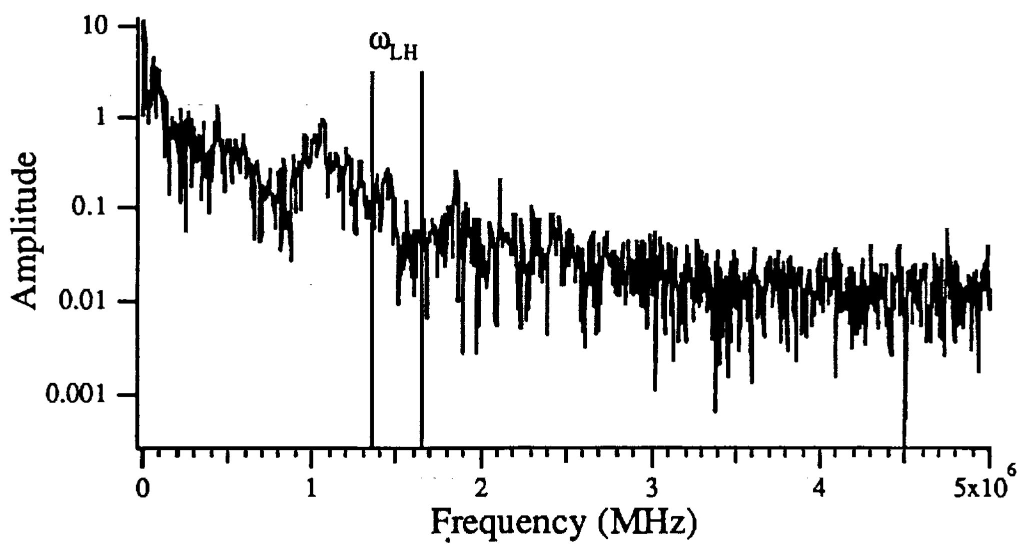


Fig. 2. Spectrum of ion saturation current fluctuations 1 mm from anode lip. From operation at 8 kA, 4 g/s argon.

Improved MPD Thruster Model

- Two-Dimensional with Axial Symmetry
- Two Temperatures
- Heat Transfer
- Nonideal Ion Equation of State (Choueiri)
- Finite Ionization Rate (Randolph)
- Variable Geometry (Wunsch)

New Numerical Method

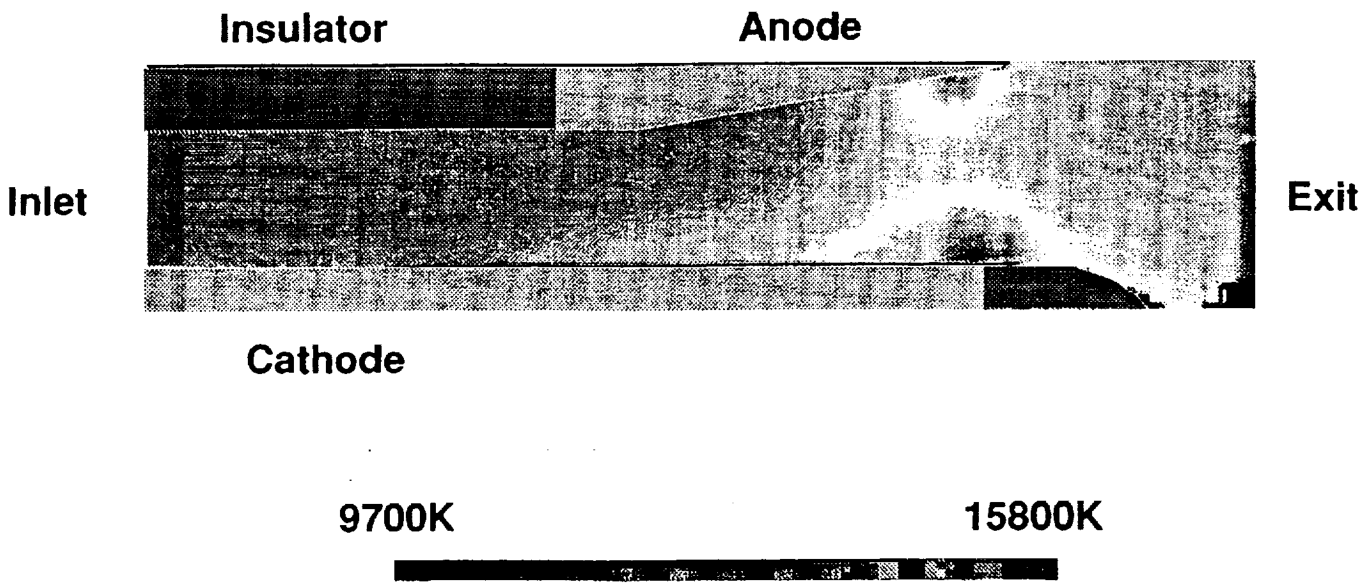
For the Conservation Equations:

- Finite-Volumes Discretization with Artificial Dissipation (Jameson)
- Euler Forward Stepping Scheme
- Multiple Grid Iteration

For the Magnetic Field Equation:

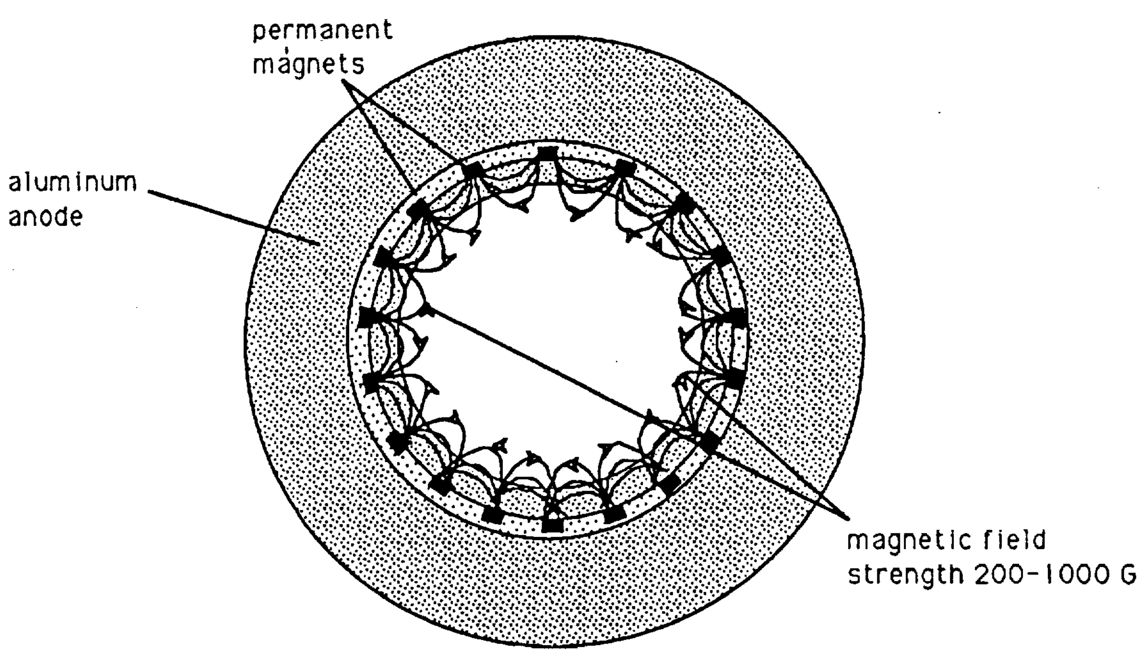
Nonlinear Jacobi Iterative Solution

Electron Temperature

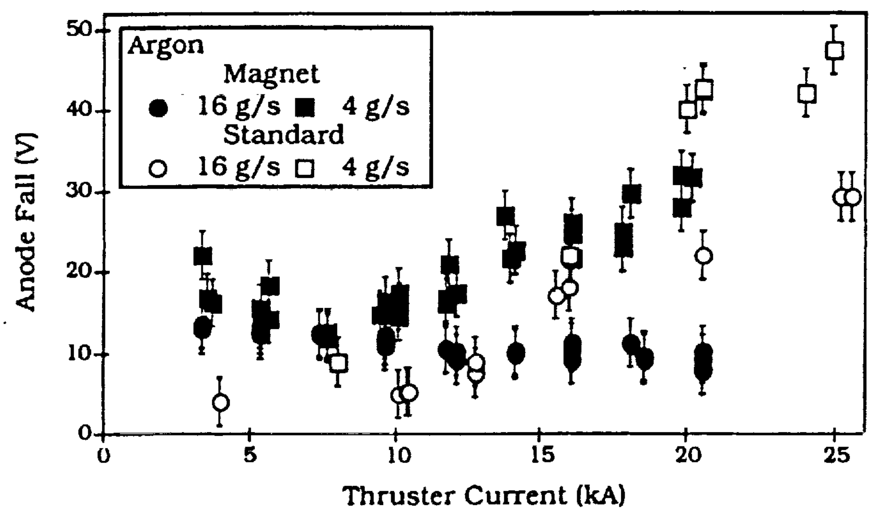


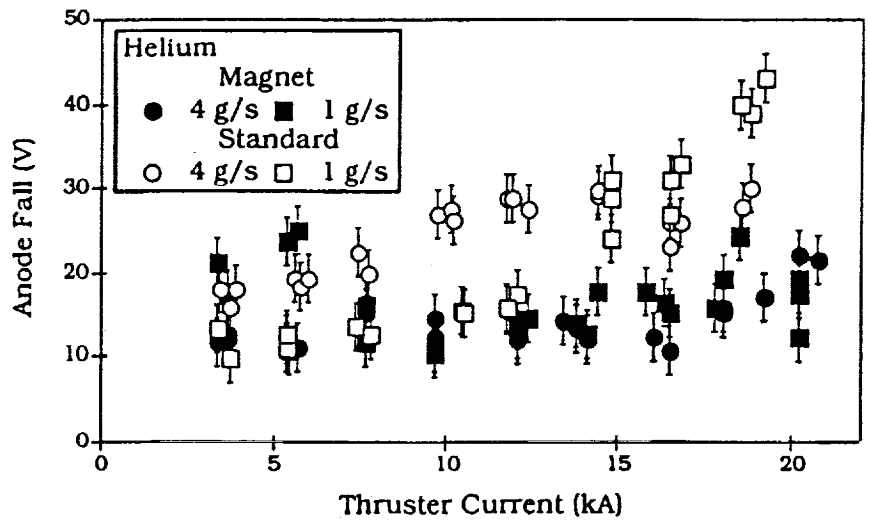
Concept

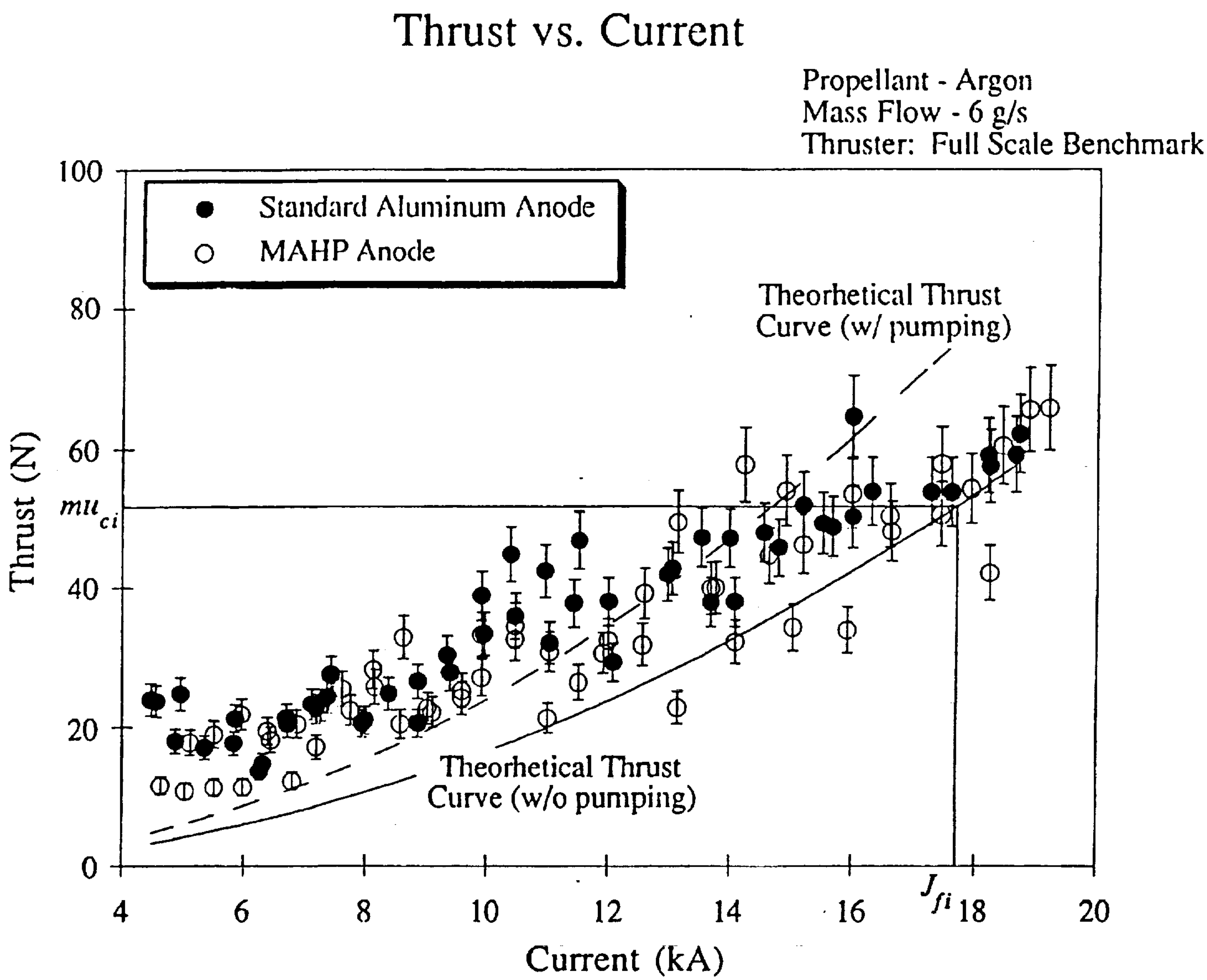
To Reduce the Induced Azimuthal Magnetic Field by Adding " Field Cancelation Zones" Near the Anode.



Anode Fall vs Thruster Current

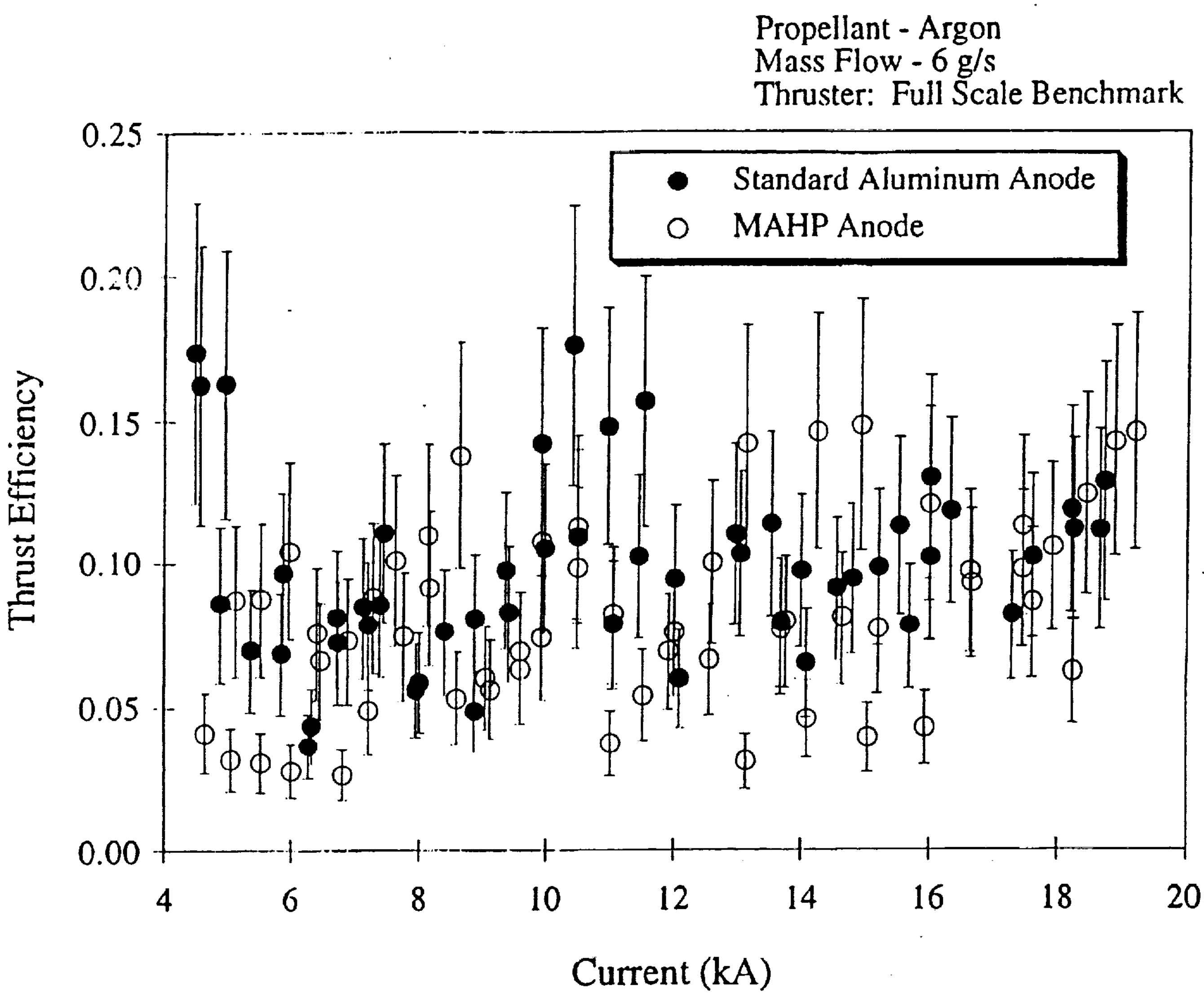


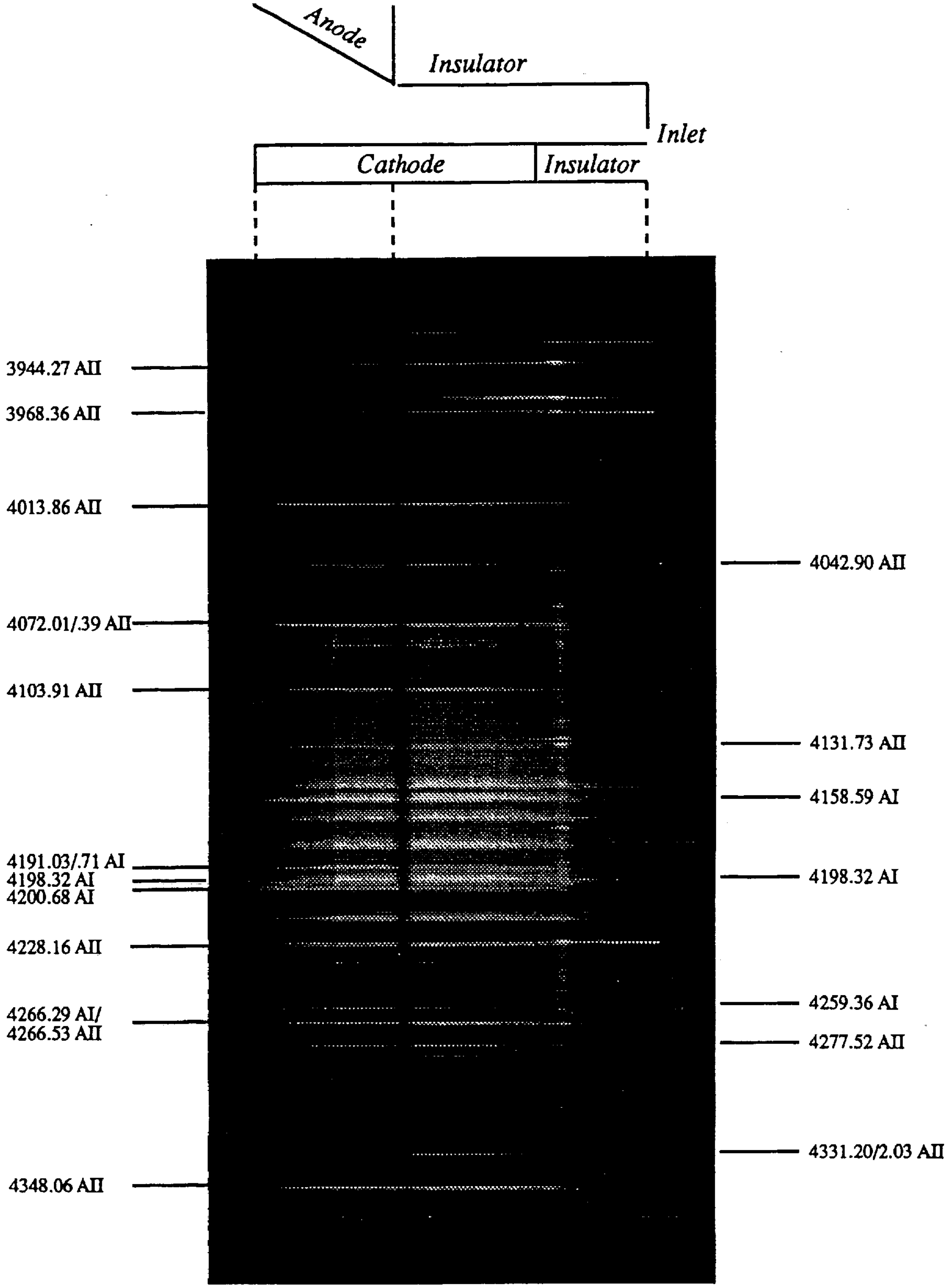




Thrust vs. Current
Propellant - Argon
Mass Flow - 6 g/s
Thruster: Full Scale Benchmark
Standard Aluminum Anode
MAHP Anode
Theorhetical Thrust
Curve (w/ pumping)
Theorhetical Thrust
Curve (w/o pumping)
Thrust (N)
Current (kA)
mu_ci
J_fi
0
20
40
60
80
100
4
6
8
10
12
14
16
18
20

Thrust Efficiency vs. Current

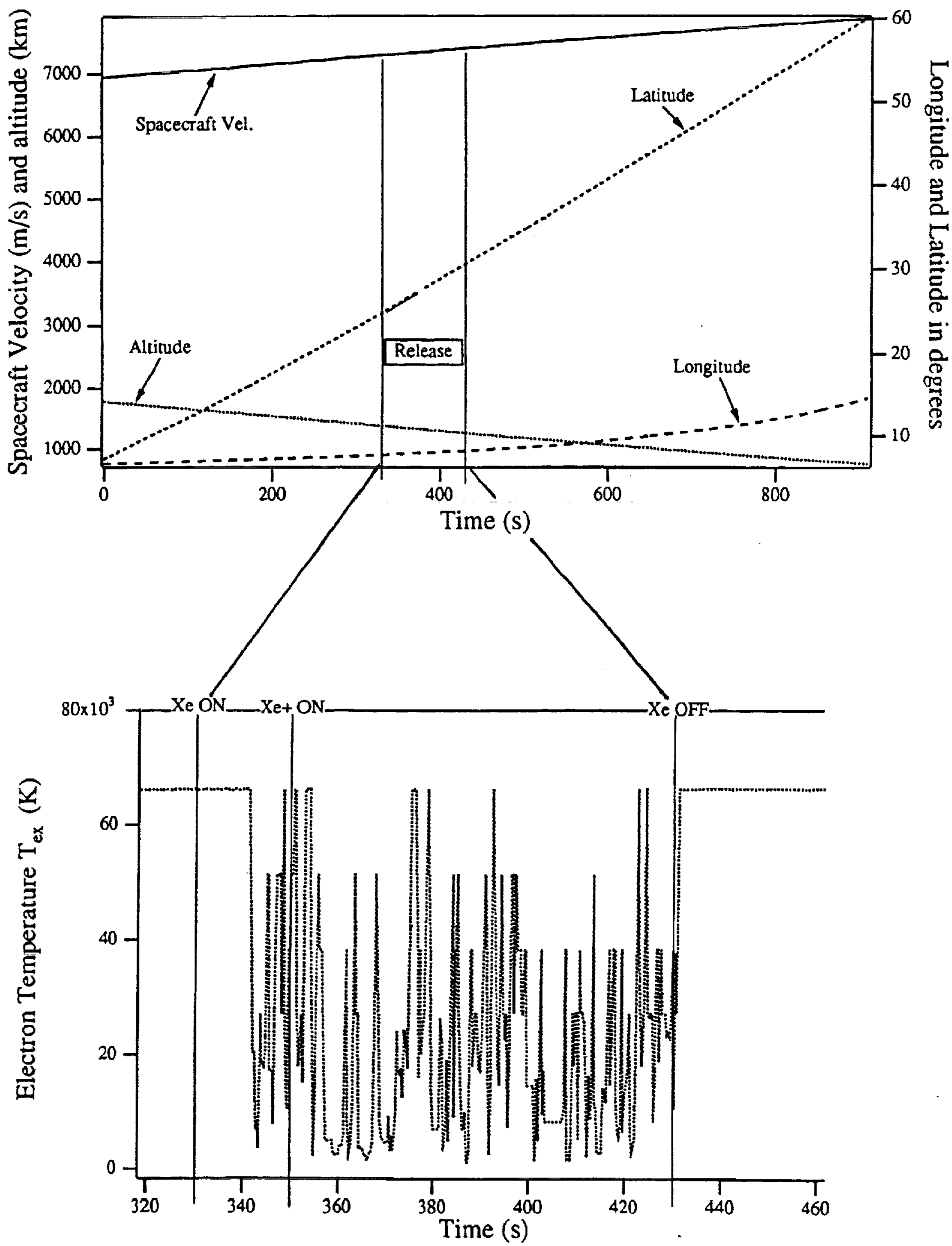




3944.27 Å to 4348.06 Å spectrum of the MPD thruster interelectrode region. Current attachment isolated downstream on the cathode to observe the initial ionization phase: Argon Mass Flow = 7 mg/s, Current = 260 A.

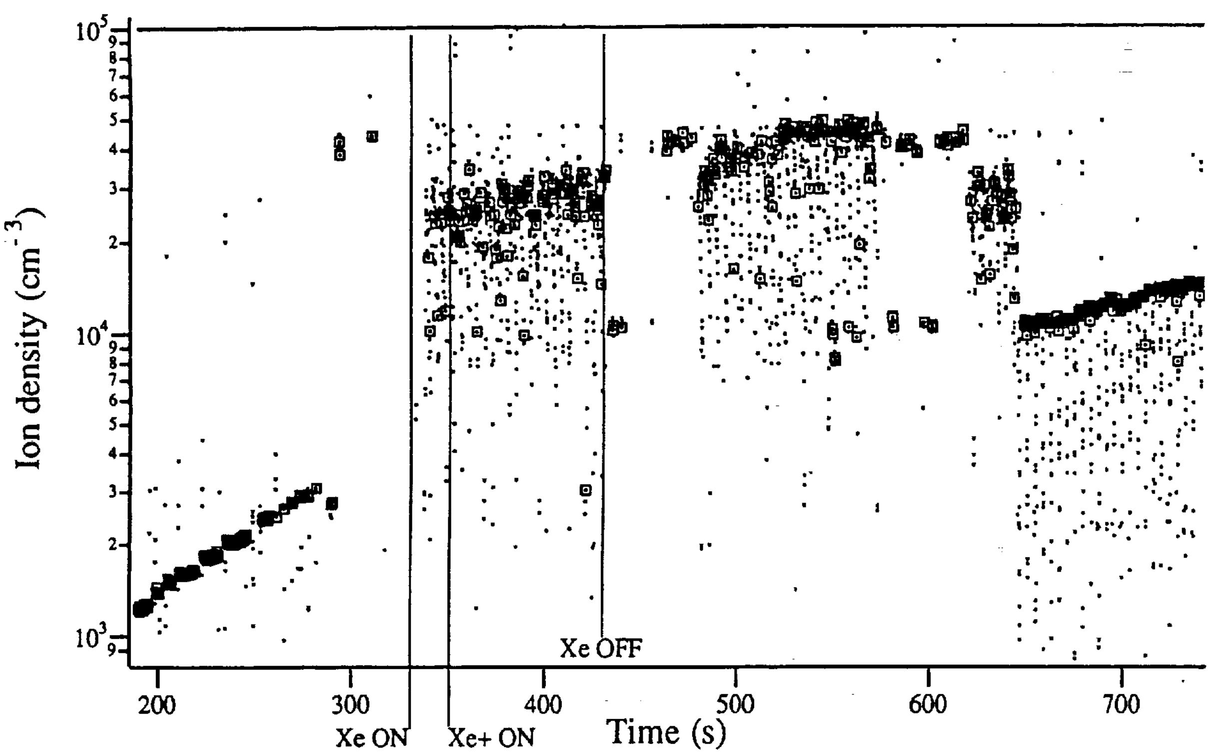
Spacecraft Orbital Parameters

During Experiment APEX/CIV-NO1



Plasma Density

During Experiment APEX/CIV-NO1



LITHIATED DISPENSER CATHODE RESEARCH

PAST RESEARCH

Polk, Myers

- Steady State erosion due primarily to sublimation
- Sublimation varies exp (T)
  T varies exp (work function)

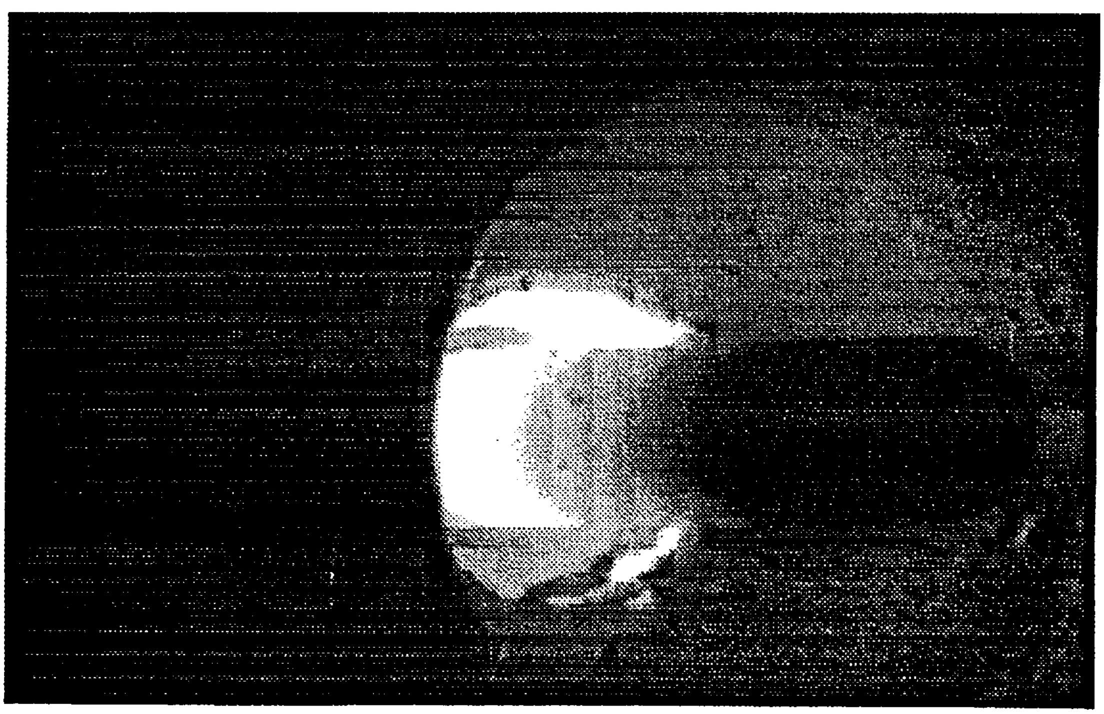
Chamberlain

- Electropositive Surface Layers improve Lifetime of Cathode
- Significant lowering of cathode temperature during steady state
- Cold cathode pitting is not observed

LITHIATED DISPENSER CATHODE RESEARCH

Objectives

1. Validate dispenser cathode design
2. Measure cathode surface temperature optically using CCD camera
3. Characterize cathode thermal behavior and correlate with thruster performance



Sample CCD picture from thruster run

Future Research Activities at EPPDyL

* **Performance characterization** of MPD thrusters with various propellants (hydrogenic propellants), various anode and cathode implementations using the laboratory's thrust stand.

* **Numerical simulations** of real MPD thrusters with various propellants, various anode and cathode implementations including non-equilibrium effects and anomalous transport.

* Further experimental and theoretical investigations of the extent of the role of **micro-turbulence** in **frozen flow** and **anode losses.**

* Feasibility study of **active turbulence suppression schemes.**

* Investigations of the nature and dependences of the dominant **ionization mechanism** through further **spectroscopic** measurements and active **space experiments.**

* Validation of the **lithiated cathode** concept.

* Synthesis, using the results of all the above activities, of practical **design criteria** for higher efficiency and longer lifetime MPD thrusters.

Appendix A. Workshop Agenda

Location

The 2nd Magnetoplasmadynamic Thruster Technology Workshop will be held in Rm 225 of the NASA Lewis Research Center Administration Building. Maps and hotel listings are attached. Visitors requiring badges must pick them up at the Main Gate.

In order to maximize the productivity of the meeting, we ask that the presenters bring 30 copies of their presentations. As was done last year, a volume will be generated incorporating the presentations and a summary of the group discussion.

Agenda

8:30: Welcome
Dave Byers, NASA Lewis Research Center

8:35 Introduction
Roger Myers, Sverdrup Technology, NASA Lewis Research Center

8:40 Transportation and Platforms Program Perspectives
Gary Bennett, NASA Headquarters

8:50 Low Thrust Propulsion Program Objectives
Frank Curran, NASA Headquarters

9:00 Mission Analysis and Systems Implications
James Gilland, Nuclear Propulsion Office

9:30 Jet Propulsion Laboratory

10:00 Lewis Research Center

10:30 Los Alamos National Laboratory

11:00 Massachusetts Institute of Technology

11:30 Ohio State University

12:00 - 1:00 Lunch

1:00 OLAC/Phillips Laboratory

1:30 Princeton University

2:00 Break

2:30 - 5:30 Group Discussion

A. Experimental Program
- Summary of progress made in past year
- Suggested testing/diagnostics
- Establish next years goals, intermediate milestones, and suggested approaches.

B. Theoretical Program
- Summary of progress made in past year
- Benchmark geometries and operating conditions
- Establish next years goals, intermediate milestones, and suggested approaches.

5:30 Summary
Roger Myers, Sverdrup Technology, NASA Lewis Research Center

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13. ABSTRACT *(Maximum 200 words)*

The Second Magnetoplasmadynamic (MPD) Thruster Workshop was held at the National Aeronautics and Space Administration (NASA) Lewis Research Center on May 19, 1992. There were 32 participants, including experts from NASA, the Department of Energy (DOE), the Department of Defense (DOD), and academia. Six government laboratories and six universities were represented at the workshop, the purpose of which was to review technical progress made since the last meeting held at NASA Headquarters in 1991 and discuss plans for future work. Specifically, the meeting focussed on progress made in establishing performance and lifetime expectations of MPD thrusters as functions of power, propellant, and design; models for the plasma flow and electrode components; viability and transportability of quasi-steady thruster testing; engineering requirements for high power, long life thrusters; and facilities and their requirements for performance and life testing.

14. SUBJECT TERMS

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