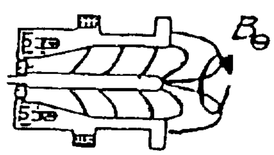
SCALING AND APPLIED FIELD STUDIES OF MPD THRUSTERS WITH LASER DIAGNOSTICS

Thomas M. York
The Ohio State University
Columbus, Ohio

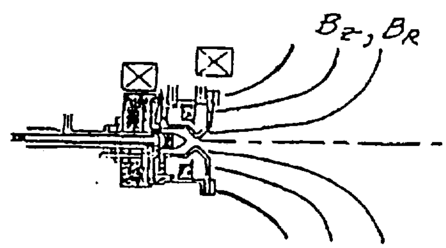
Scaling of Plasma Thrusters- Match High Efficiency Thrusters To Available Power

Self-Field MPD



Erosion Limited
Power Limited
Efficiency Limited
Physical Mechanisms for Limits not Understood
Self-Field Magnetic Expansion Effects Interdependent with Gas Heating

1/4-Scale Applied-Field MPD



Fields Influence Erosion
Fields allow Better Expansion at Low Power
Fields Enhance Expansion and Efficiency
Physical Mechanisms not yet Understood
Applied-Field Magnetic Nozzle Independently Controllable from Gas Heating Source

Scaling Of Arcs And MPD-Arcs

Properties And Functions:

Size: L

Mass Flow: $\dot{m}/Acs$

Em Velocity: $Uem = \left(\frac{I^2}{\dot{m}}\right)\frac{\mu o}{4\pi}\ln\left(\frac{Ra}{Rc}\right)_{EFF}$ $\quad \alpha \; \frac{I^2}{\dot{m}} = \frac{j^2 r^2 z^2}{\dot{m}} \quad \alpha \; \frac{\vec{j} \times \vec{B}}{\dot{m}/Acs}\, z$

Force Density: $j \times B$ $\quad \alpha \; \frac{I^2}{r^2 z} = j^2 z$

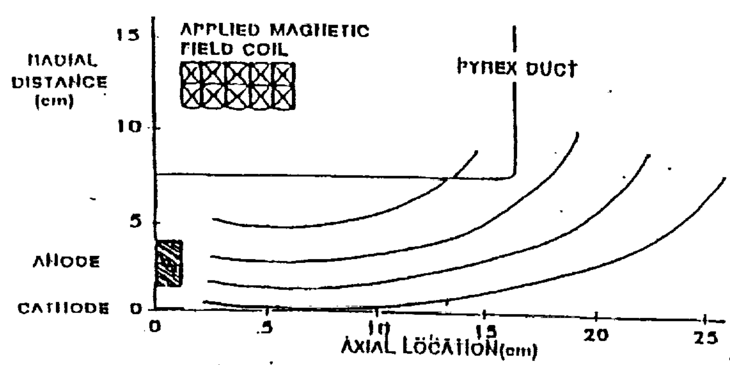
Power: $IV = I^2R$

Eth Velocity: $Ueth = \left(\frac{2I^2R}{\dot{m}}\right)^{1/2}$ $\quad \alpha \left(\frac{I^2}{\dot{m}} R\right)^{1/2} \quad \alpha \left(\frac{j^2 z^2}{\dot{m}/Acs} R\right)^{1/2}$

1/4-Scale Thruster:
($\vec{j} \times B$ and $\dot{m}/Acs$ constant)

1F	$L = L_{fs}/4$	$I_{1/4} = I_{fs}/8$	
1F	$L = L_{fs}/4$	$j_{1/4} = j_{fs} \times 2$	
1F	$L = L_{fs}/4$, R = const.	$U_{eth} = U_{eth}$ (fs)/2	(Electrode drop dominant)
1F	$L = L_{fs}/4$, σ = const.	$U_{eth} = U_{eth}$ (fs)	(Plasma drop dominant)

Magnetic Nozzle Studies



1/4 SCALE THRUSTER, FIELD COIL AND APPLIED MAGNETIC FIELD LINES

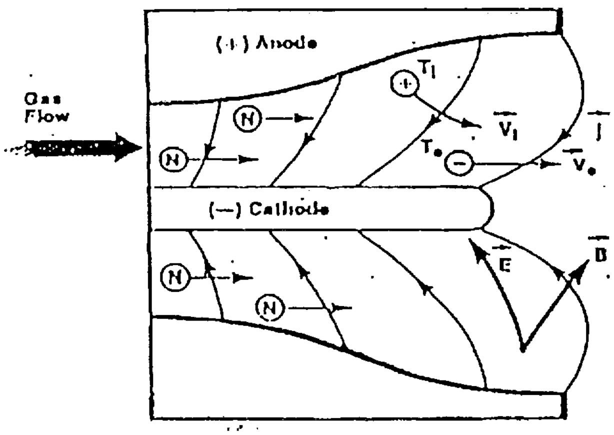
Reported:

- Self-Field plasma expands to low pressure in 5 cm (plasma $\dot{m}$ lost). Applied-field plasma expansion is controlled and has large $\int pdA$ thrust.
- Applied fields can be optimized for Uex max or high thrust with low Uex. This will allow optimization of Uex for mission requirements.

Being Completed:

- New switches and battery supply allow: .1-2sec nozzle field generation to study effects of field penetration into thrust chamber
- New coil design will change nozzle shape to study effects of extended length, gradual expansion, detachment, etc.

Advanced Diagnostic Techniques Needed For Obtaining Particle Velocity, Density, Temperature And Current Distributions In Plasma Thrusters



Need to Measure:

- Electron, Ion and Neutral Densities
- Electron and Ion Temperatures
- Current Densities
- Species
- Potential and Magnetic Field
- Velocity Profiles

Non-Intrusive Laser Diagnostics For Arcs And MPD-Arcs

THOMSON SCATTER FOR Ne , Te
2J Ruby system used to measure Ne , Te on 1/4 scale
Confirmed Ne , Te indications of Langmuir in B
Established point reference for multi-beam interferometer

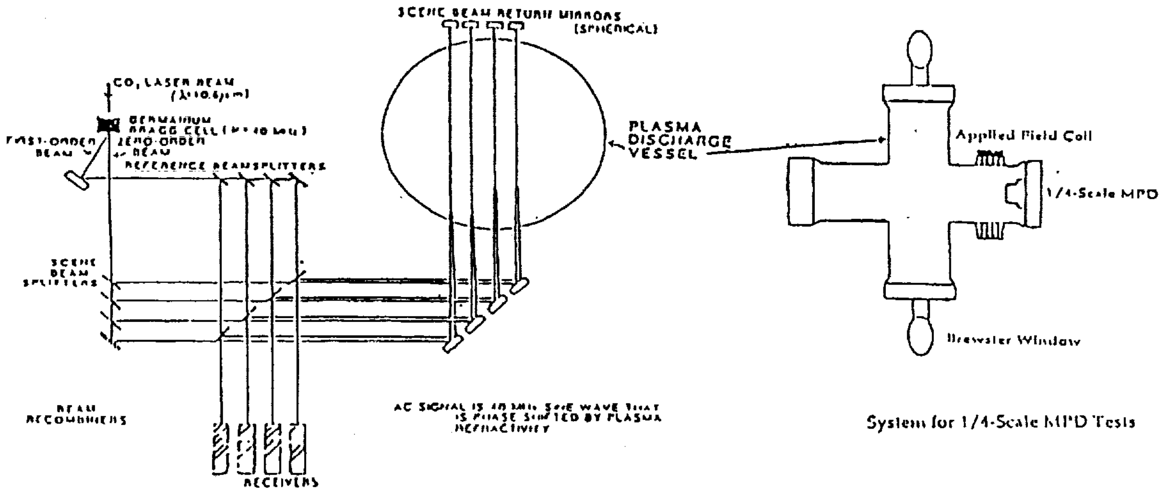
THOMSON SCATTER FOR (ELECTRON) FLOW VELOCITY
2J Ruby system used to get $V \gtrsim$ Sonic on experiment
Electron velocity confirmed equal to ion velocity
Could be applied to ARC and MPD-ARC

MULTIBEAM INTERFEROMETER FOR Ne(r) = f(z) PROFILES
50W CO2 CW system being used with 4 beams on chords
Abel inversion allows Ne(r)
Allows comprehensive view of applied field effects

DIAGNOSIS OF Ne FLUCTUATIONS FOR TRANSPORT STUDIES
50W CO2 CW System can be used for ARC and MPD-ARC studies
FIR wavelengths and new detectors possible
Fluctuations between .01 and 1. cm with 1 kHz - 10GHz in plasma with 10^{16} - 10^{17} cm^{-3} possible

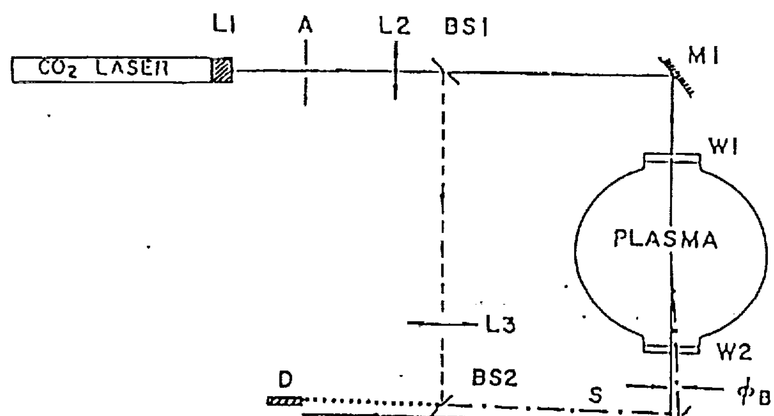
MAGNETIC FIELD AND CURRENT DENSITY WITH FARADAY ROTATION
Laser beam rotated ∝ B, as $\theta < \lambda_0^2$ Ne B dZ
Long λ_0 generates high sensitivity (118.8 m possible)
Need interferom. determination of Ne dZ to unravel

Schematic of Multi-Beam Interferometer For Electron Density Profile Determination



System for 1/4-Scale MPD Tests

Schematic of Diagnostic System to Determine Density Fluctuations Magnitude and Orientation To Define Anomalous Transport



A schematic diagram for small angle CO_2 laser scattering from a plasma. A rotating mirror RM scans the scattered radiation S at angle ϕ_B to be coincident with the LO beam at BS2 and detector. The fluctuation of wavelength λ is determined from $\phi_B = 2\mathrm{Sin}^{-1}(\lambda_o / 2\lambda)$