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SPACE PROPULSION TECHNOLOGY DIVISION

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MPD THRUSTER TECHNOLOGY

56005682

ROGER M. MYERS

SVERDRUP TECHNOLOGY
NASA LEWIS RESEARCH CENTER

MAY 16, 1991

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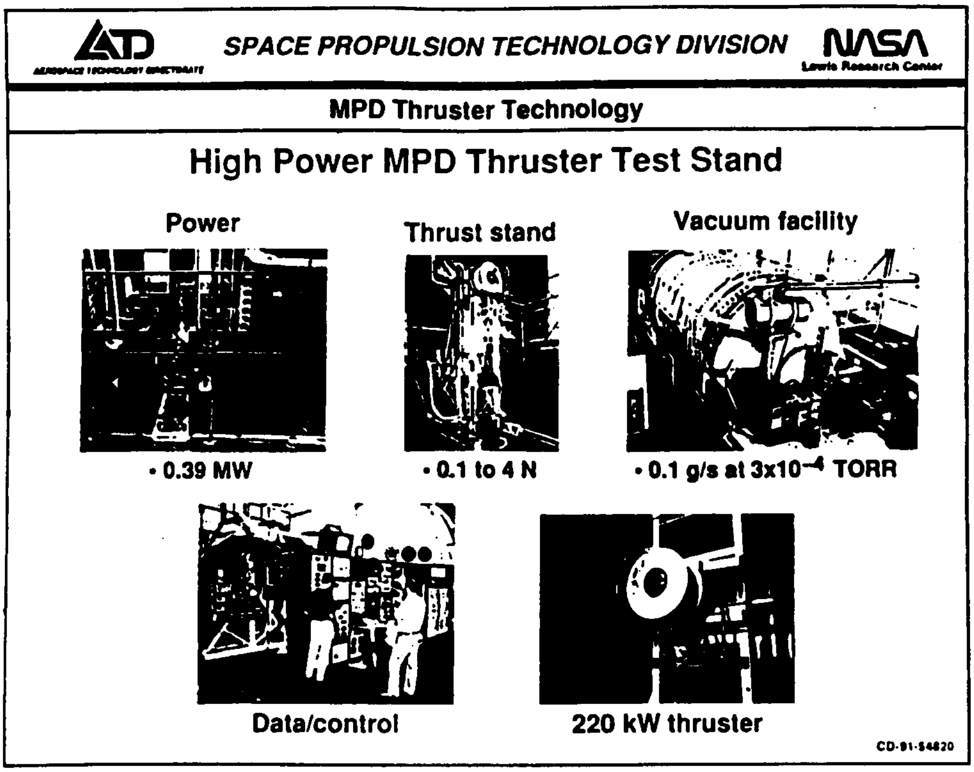
IN-HOUSE PROGRAM OVERVIEW

- RE-ESTABLISHED IN 1987
- FOCUSSED ON STEADY-STATE THRUSTERS AT POWERS < 1 MW
- DEVELOPED PERFORMANCE MEASUREMENT AND DIAGNOSTICS TECHNOLOGIES FOR HIGH POWER THRUSTERS
- DEVELOPING MHD CODE
- GOALS ARE TO ESTABLISH
    - PERFORMANCE AND LIFE LIMITATIONS
    - INFLUENCE OF APPLIED FIELDS
    - PROPELLANT EFFECTS
    - SCALING LAWS



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MPD Thruster Technology

High Power MPD Thruster Test Stand

Power

- 0.39 MW

Thrust stand

- 0.1 to 4 N

Vacuum facility

- 0.1 g/s at 3×10^{-4} TORR

Data/control

220 kW thruster

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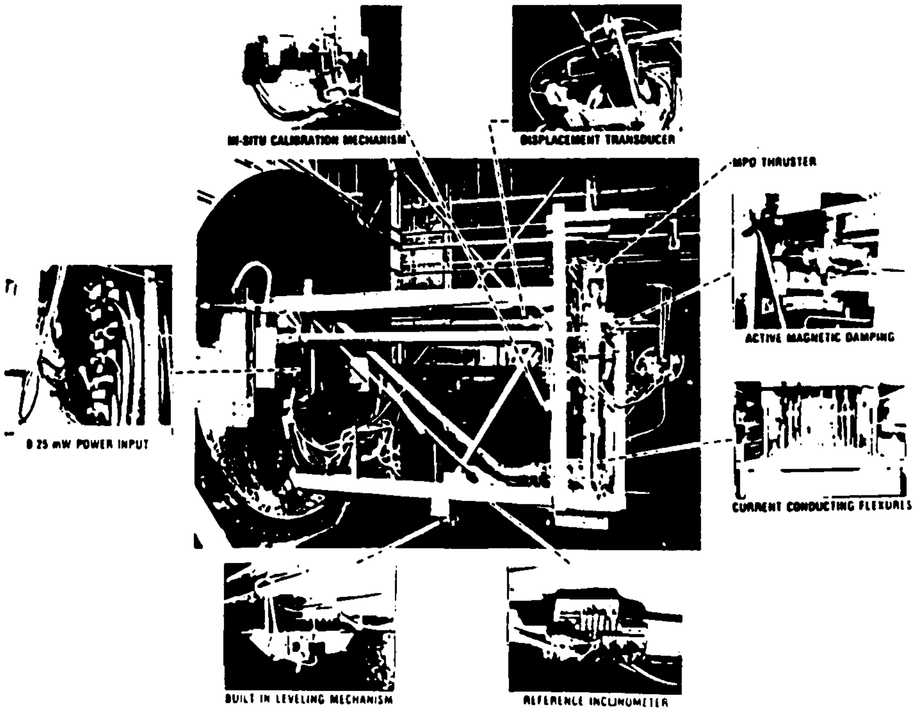
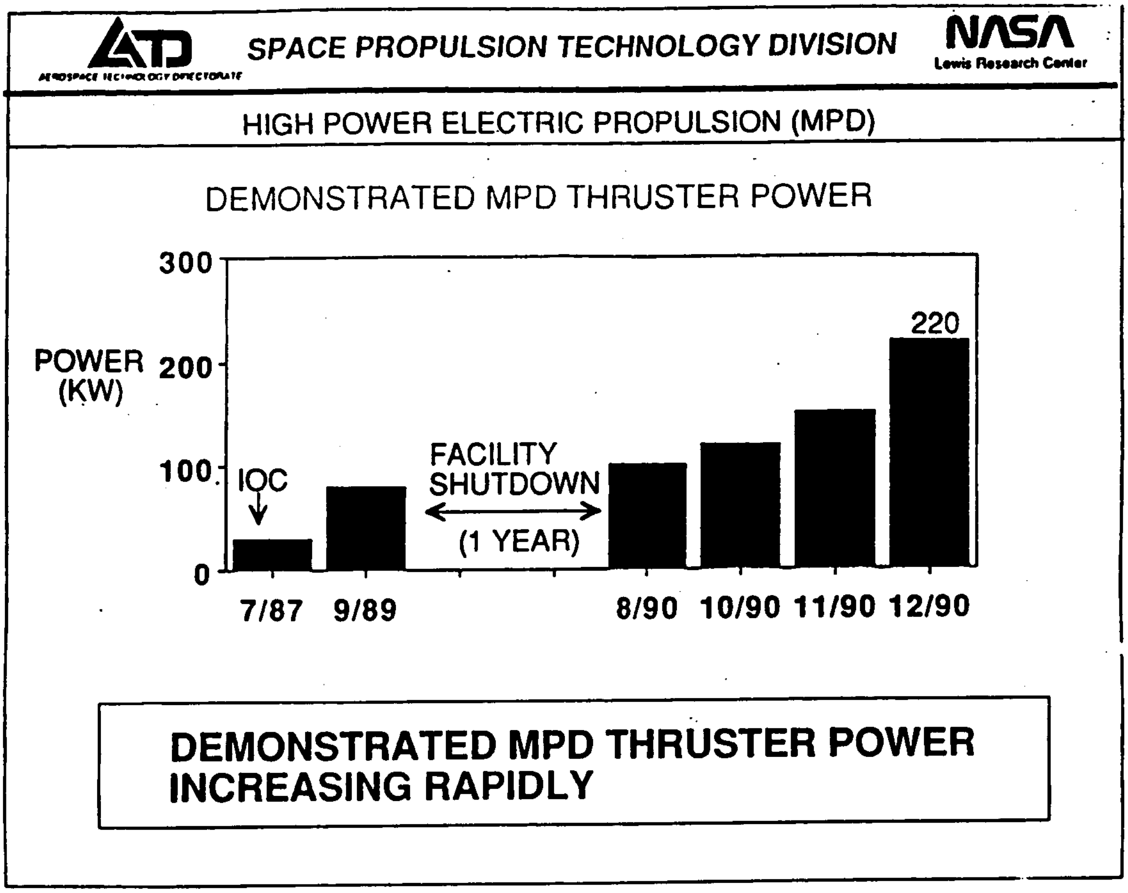
MPD THRUSTER TEST STAND





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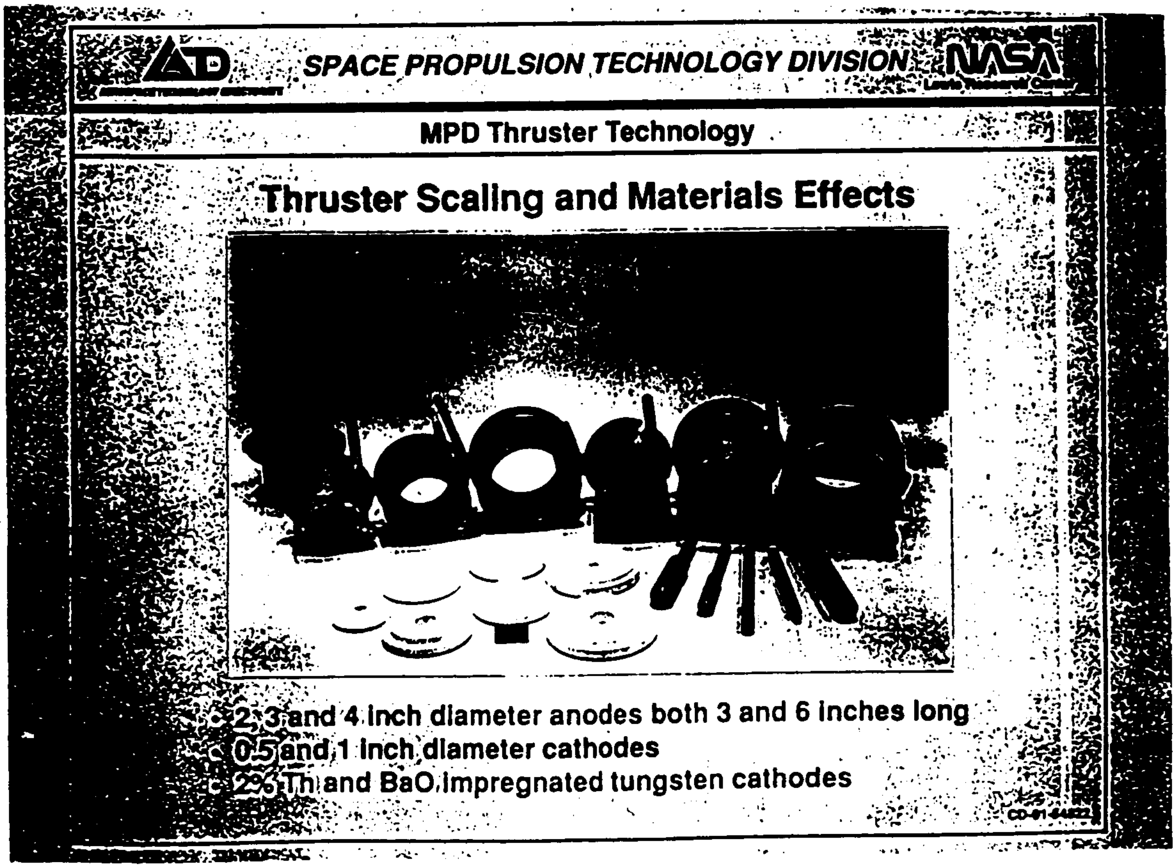
HIGH POWER ELECTRIC PROPULSION (MPD)

DEMONSTRATED MPD THRUSTER POWER

DEMONSTRATED MPD THRUSTER POWER INCREASING RAPIDLY



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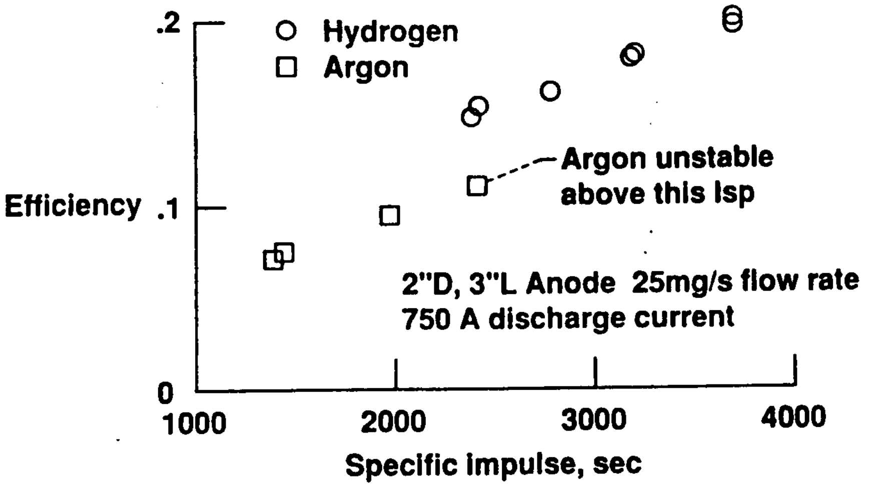
MPD Thruster Technology

Thruster Scaling and Materials Effects

- 2, 3 and 4 inch diameter anodes both 3 and 6 inches long
- 0.5 and 1 inch diameter cathodes
- 2% Th and BaO impregnated tungsten cathodes

MPD Thruster Technology

Performance Measured With Hydrogen and Argon



Argon unstable above this Isp

2"D, 3"L Anode 25mg/s flow rate
750 A discharge current

Performance dramatically improved with hydrogen
- Efficiency increased by 2X
- I_{SP} increased by 50%

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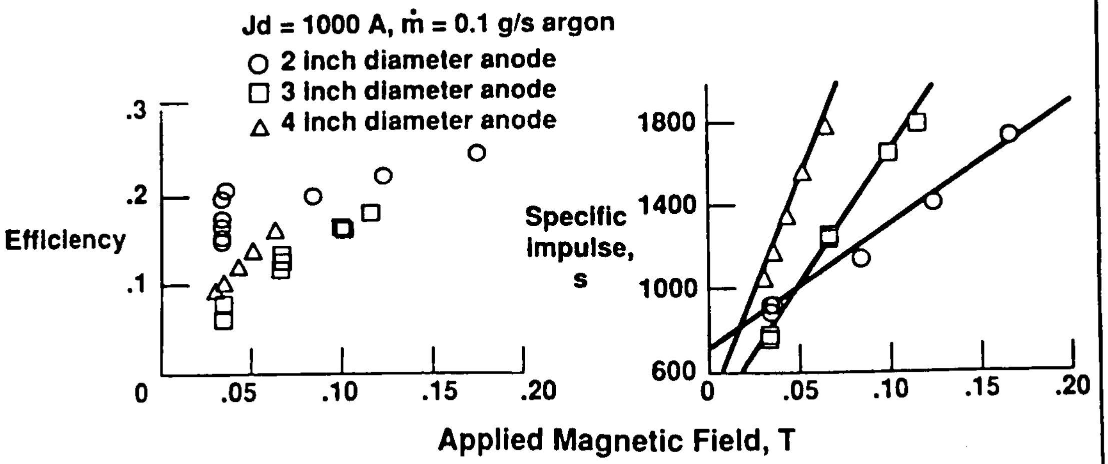
MPD Thruster Technology

Thruster Performance

Geometry and Applied Field Effects



- Efficiency increases with applied field strength
- Specific impulse increases with both anode radius and applied field strength

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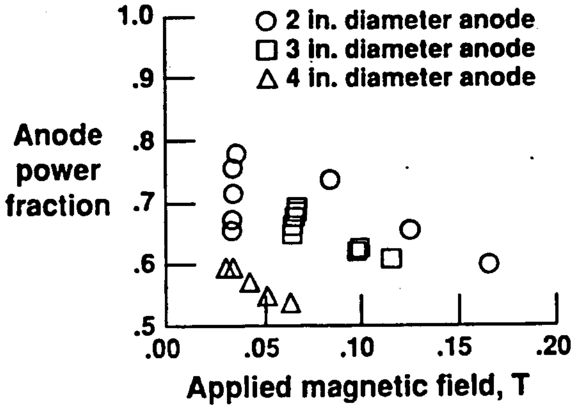
MPD Thruster Technology

Anode Power Deposition
Applied Field and Geometry Effects



Increasing applied field strength and anode diameter decrease anode power fraction

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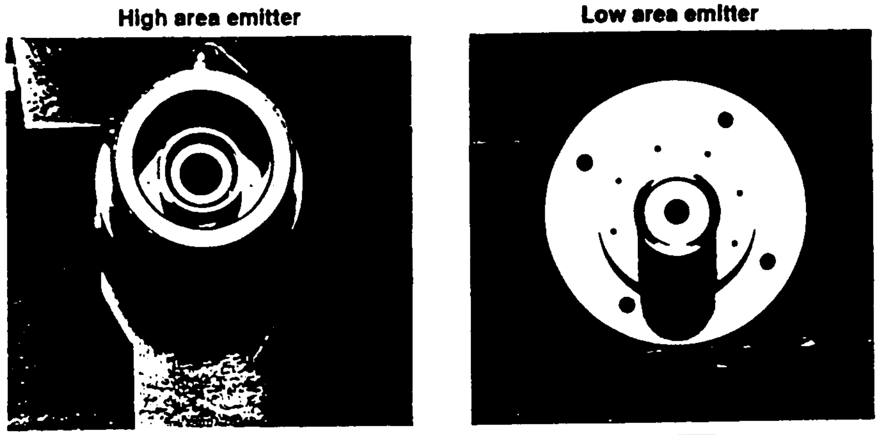
HIGH POWER ELECTRIC PROPULSION (MPD)

MPD THRUSTER HIGH CURRENT HOLLOW CATHODE TECHNOLOGY


High area emitter

Low area emitter

Three hollow cathode assemblies fabricated and prepared for evaluation

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MPD Thruster Technology

Scaling Issues

- Megawatt class operation required for missions of interest
- Cannot operate megawatt class steady-state in current facilities
- Must be able to correlate MW class pulsed thruster operation and steady state data
- Data must enable rational extrapolation to high power levels

How do we realistically study MPD thruster performance and life using currently available facilities?

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MPD Thruster Technology

Diagnostics

- X-Y probe positioning stand
  - Electrostatic probes
  - enclosed current contours
  - Axial applied B field distribution
- Plume imaging
  - Correlate ion density distribution with applied field
- Spectoscopy
  - Non-invasive temperature and density measurements

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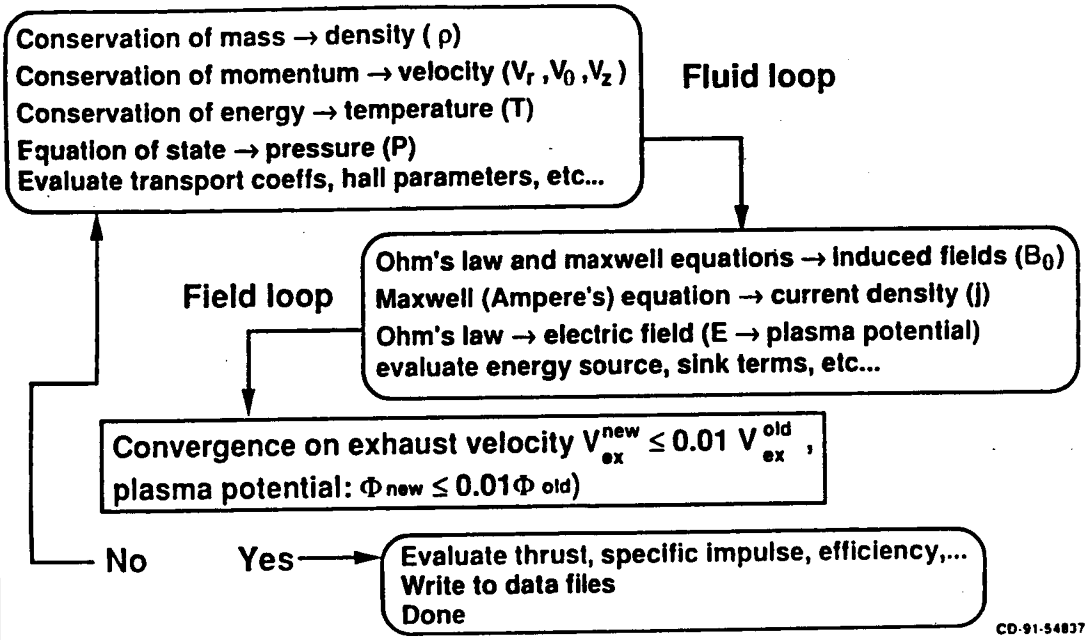
MPD Thruster Modeling

Program Outline



Conservation of mass → density (ρ)
Conservation of momentum → velocity (V_r ,V_0 ,V_z)
Conservation of energy → temperature (T)
Equation of state → pressure (P)
Evaluate transport coeffs, hall parameters, etc...

Fluid loop

Ohm's law and maxwell equations → induced fields (B_0)
Maxwell (Ampere's) equation → current density (j)
Ohm's law → electric field (E → plasma potential)
evaluate energy source, sink terms, etc...

Field loop

Convergence on exhaust velocity $V_{ex}^{new} \leq 0.01\ V_{ex}^{old}$,
plasma potential: $\Phi_{new} \leq 0.01\Phi_{old}$)

No

Yes

Evaluate thrust, specific impulse, efficiency,...
Write to data files
Done

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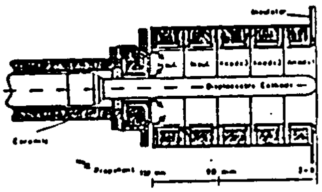
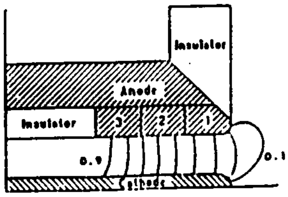
MPD Thruster Modeling

Comparison With U. Stuttgart Model/Experiment

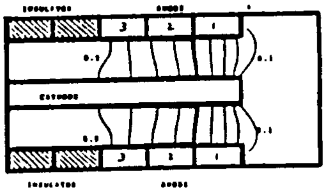
(6kA, 6 g/s)



Stuttgart-experiment



Stuttgart-model



NASA LeRC-model

Current fractions into anode segments

Segment 1:	46%	44%	51%
Segment 2:	27%	27%	22%
Segment 3:	27%	29%	27%

NASA LeRC code in agreement with Stuttgart MPDT experiment/model

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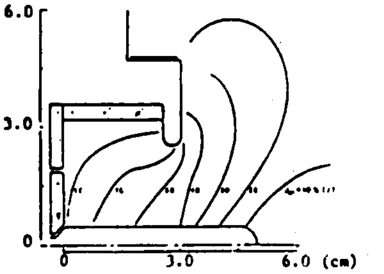
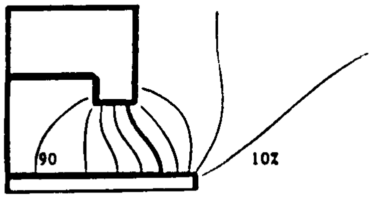
MPD Thruster Modeling

Comparison with Princeton University

Half-Scale Benchmark Thruster

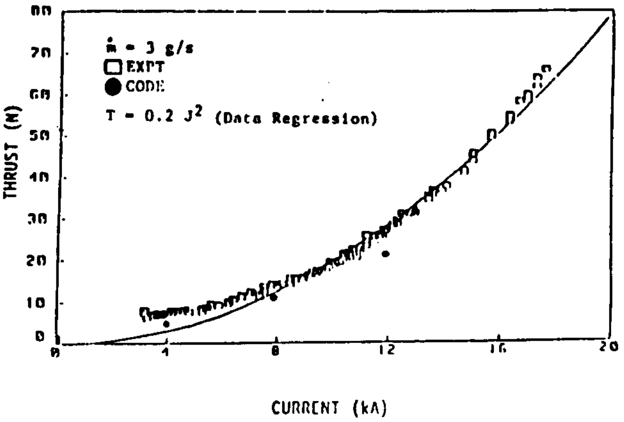


ENCLOSED CURRENT CONTOURS (MEASURED)
12.4 kA, 1.5 g/s, QUASI-STEADY OPERATION



ENCLOSED CURRENT CONTOURS (PREDICTED)
12.4 kA, 1.5 g/s, STEADY-STATE OPERATION

Thrust Characteristics



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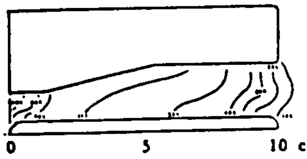
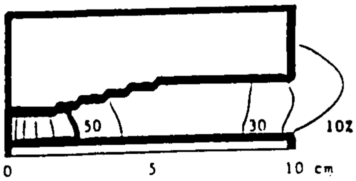
MPD Thruster Modeling

Comparison with Princeton University

Half-Scale Flared Anode Thruster

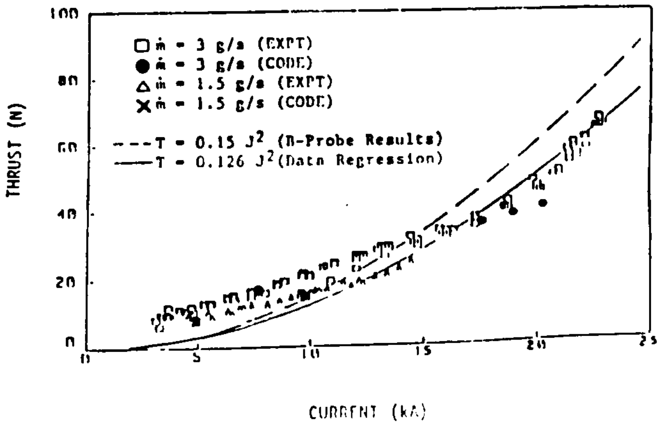


ENCLOSED CURRENT CONTOURS (MEASURED)
7.9 kA, 3 g/s, QUASI-STEADY OPERATION



ENCLOSED CURRENT CONTOURS (PREDICTED)
7.9 kA, 3 g/s, STEADY-STATE OPERATION

Thrust Characteristics



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MPD Thruster Modeling

Status

- Self-field version of MPDT code operational
  - Modest execution times 3-5 hours VAX-CPU)
  - General agreement with experimental results
  - Thruster performance evaluations underway
- Applied-field version of code under development
  - Routines for applied-B distributions incorporated
  - Preliminary testing/modification in progress

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KEY TECHNICAL ISSUES

KEY SCALING ISSUES

- TWO PRIMARY CONCERNS
  - POWER LEVEL SCALING
  - QUASI-STEADY VS. STEADY STATE
- ISSUES MUST BE ADDRESSED USING
  - THEORETICAL MODELS TO ESTABLISH TRENDS AND DEPENDENCIES
  - HGIH FIDELITY PERFORMANCE MEASUREMENTS
  - DETAILED DIAGNOSTICS OF PLASMA AND ELECTRODE PROCESSES USED TO:
    A. ESTABLISH FUNDAMENTAL RELATIONSHIPS
    B. VERIFY MODELS

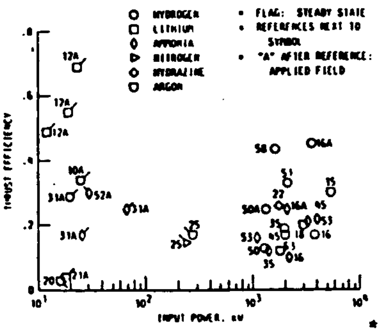
PERFORMANCE EXPECTATIONS:

MUST EVALUATE EFFECTS OF :
- PROPELLANT AND APPLIED FIELD
- ELECTRODE SIZE AND SHAPE
- PROPELLANT INJECTION

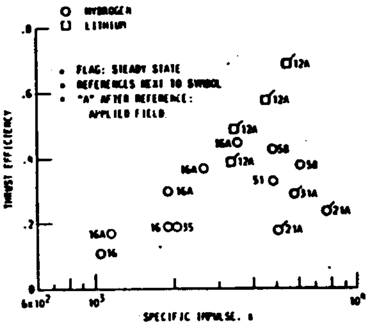
RELATION BETWEEN QUASI-STEADY AND STEADY-STATE:

- MUST ESTABLISH DATA BASE WITH CORRECT PROPELLANT IN THE APPROPRIATE OPERATING RANGE ($J^2/\dot{m}$?)
- MUST MEASURE PERFORMANCE, CURRENT DISTRIBUTIONS, PLASMA AND ELECTRODE PARAMETERS

PERFORMANCE EXPECTATIONS



Thrust efficiency as a function of power and propellant.

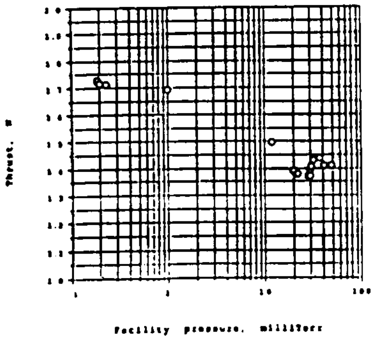


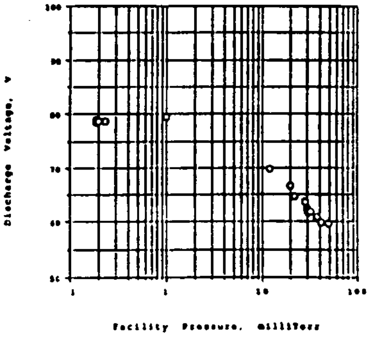
Performance of hydrogen and lithium thrusters.

- NOT CORRELATED WITH POWER
- STRONGLY INFLUENCED BY
  - PROPELLANT CHOICE
  - APPLIED OR SELF-FIELD

* Sovey, J. and Mantenieks, M. "Performance and Lifetime Assessment of Magnetoplasmadynamic Arc Thruster Technology", J. Propulsion and Power, Vol.7, No. 1, Jan-Feb 1991

FACILITY REQUIREMENTS

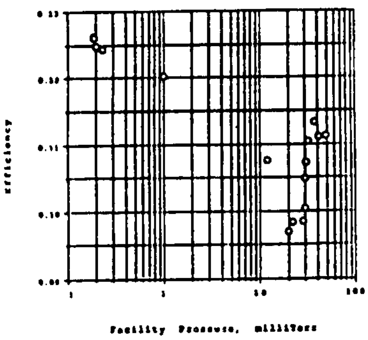




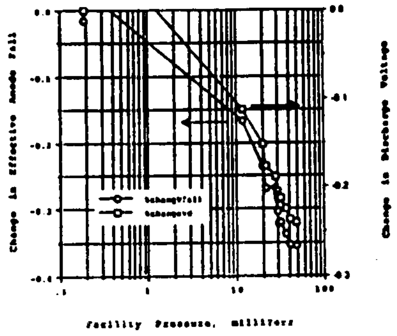
4" D, 3"L ANODE, 0.1 G/S ARGON, 1500 A DISCHARGE, Bz = .1 T

FACILITY REQUIREMENTS

EFFICIENCY



CHANGE IN V_{an} AND V_d



Similar anode heat xfer effect observed by Saber with self-field thrusters

4" D, 3"L ANODE, 0.1 G/S ARGON, 1500 A DISCHARGE, Bz = .1 T

POTENTIAL MPDT FACILITIES

FY	FACILITY	THRUSTER POWER, MW H2	AR	OPERATION TIME, HR	ESTIMATED COST, $K
PRESENT	LERC T5,T6	0.1 (DEM)	0.22 (DEM)	CONT	-------
1992	LERC T5	0.7-1	1	1 - 2	250 K
1993	LERC T5	1 - 1.5	2	4 - 6	400 K
1995	LERC T6	1 - 1.5	2	'CONT.'	3500 - 5000
1995	LLNL MFTF	1-5		'CONT.'	5000 - 7000
1998	LERC T6	1 - 5	1 - 5	'CONT.'	TBD

MATERIAL LIMITATIONS

ANODE:

- MEASURED HEAT FLUX AT HIGH POWER > 5 KW/CM^2 *
  - LITHIUM HEAT PIPES LIMITED TO < 0.5 KW/CM^2
  - OPTIMIZED BEAM DUMP (Cu) LIMITED TO ~ 5 KW/CM^2
  - SSME THROAT HEAT FLUX ~ 16 KW/CM^2 (relevance?)

CATHODE:

- CURRENT DENSITIES AT HIGH POWER > 100 A/CM^2*
  - LONG LIFE CATHODES LIMITED TO CURRENT DENSITIES ≤ 20 A/CM^2 (LOW W.F. TWT CATHODES)

INSULATORS:

- KNOWN TO FAIL AFTER PROLONGED EXPOSURE TO UV AND HIGH TEMPERATURE

- **WE MUST SELECT GEOMETRIES WHERE PERFORMANCE AND ENGINEERING LIMITS CAN BE EVALUATED**

* PRINCETON UNIVERSITY

FACILITY LIMITATIONS:

- MUST MEASURE PERFORMANCE AT PRESSURES < 5 X 10^{-4} T
- FACILITY PRESSURE HAS LARGE EFFECT ON ANODE HEAT XFER, NOT CLEAR ON CATHODE

THRUSTER VIABILITY:

- SHOULD FOCUS ON DEVICES WHICH MATCH ENGINEERING LIMITS FOR:
  ANODE HEAT TRANSFER
  CATHODE CURRENT DENSITY
  INSULATOR LIMITS