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Hargus, W., "AFRL Hall Thruster Development" (BFI)

JANNAF Propulsion Meeting (Tucson, AZ, 14-16 Dec 1999)

(Statement A)



AFRL Hall Thruster Development

**AFRL/PRRS Spacecraft Propulsion Branch
USAF Electric Propulsion Group**

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AFRL Electric Propulsion Requirements



Air Force Missions (from AFSPC):

- Space-Based Radar
- Space Command
- On-Orbit Inspection

Low Power
 $P < 200 \text{ W}$

- Small Propulsion (10-200W)
- Micropropulsion (1-10W)

- Stationkeeping

Medium Power
0.5 to 1 kW Arcjets
1 to 5 kW Hall Thrusters

- Largely Commercial

Arcjets: Primex

Resistojets: TRW, Primex

Hall: ARC, Busek, Primex, TRW

Ion Thrusters: Hughes

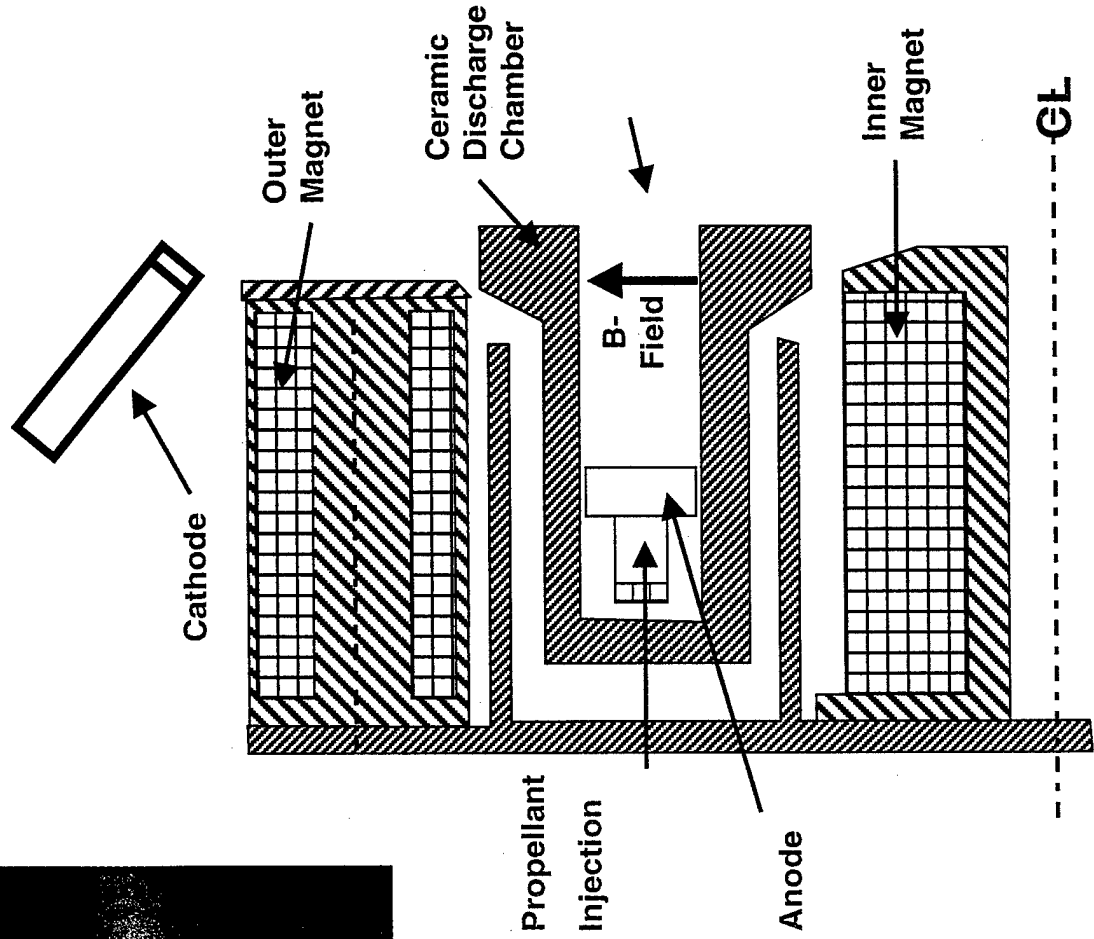
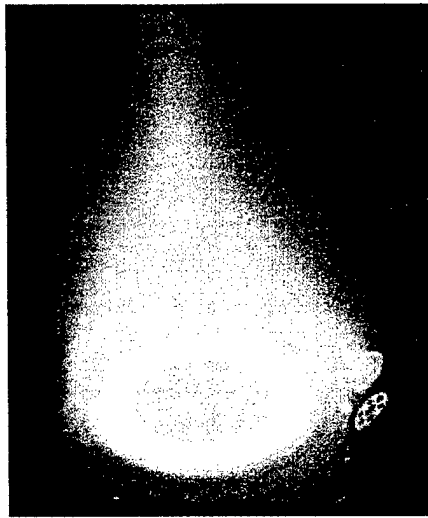
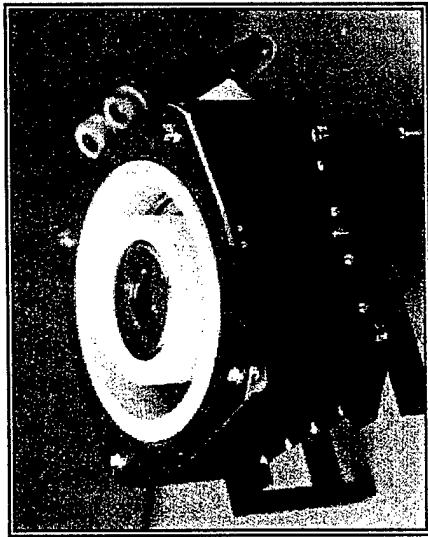
- Orbit Transfer
- On-Orbit Servicing

High Power
 $P > 10 \text{ kW}$

- Hall Thrusters



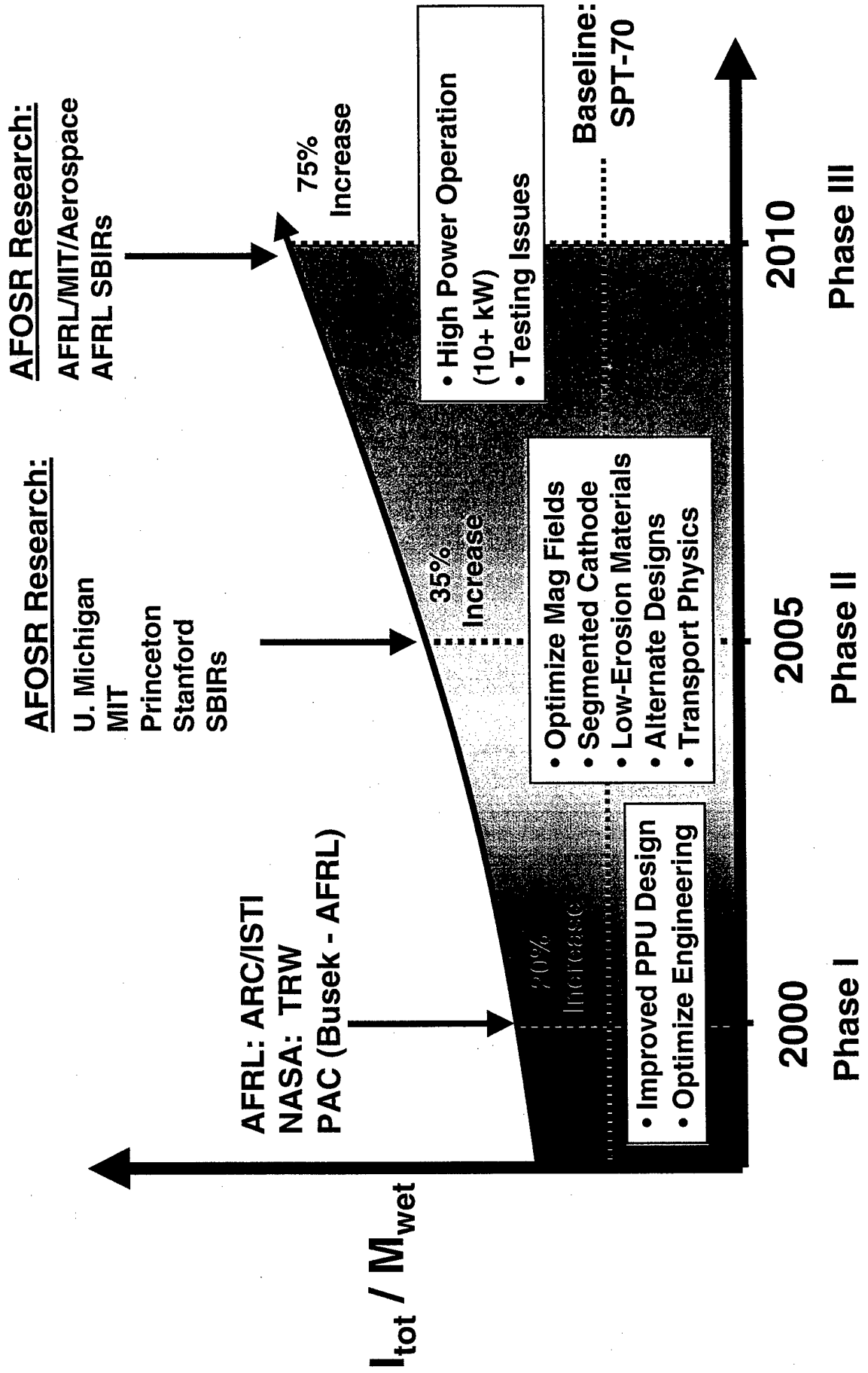
Hall Thruster System Operating Principles



1. Electrons emitted from the cathode travel toward the anode.
2. Electrons are impeded in the discharge channel by a strong radial magnetic field, causing a strong axial electric field to concentrate in this region.
4. This electric field heats the electrons, which subsequently ionize gaseous propellant (xenon) emitted near the anode.
6. The ionized gas accelerates axially through the electric field in the discharge channel, exiting the device at high speed, thus producing thrust.



AFRL IHPRPT Goals





In-House Research Resources

Advanced Hall Thruster Development

In-house FY00 budget request: \$ 405,500
Currently FY00 funded Budget: \$ 70,000 (17%)
Budgeted Man hours: 464 hrs

<u>FY 98</u>	<u>FY 99</u>	<u>FY 00</u>	<u>FY 01*</u>	<u>FY 02*</u>	<u>FY 03**</u>
0	139,000	70,000	339,000	348,000	335,000

* Projected Budgets
** Program End Date



Funding Supports

- In-house research and development: 1 researcher, 1 mechanic
- Vacuum test facility upgrades and maintenance



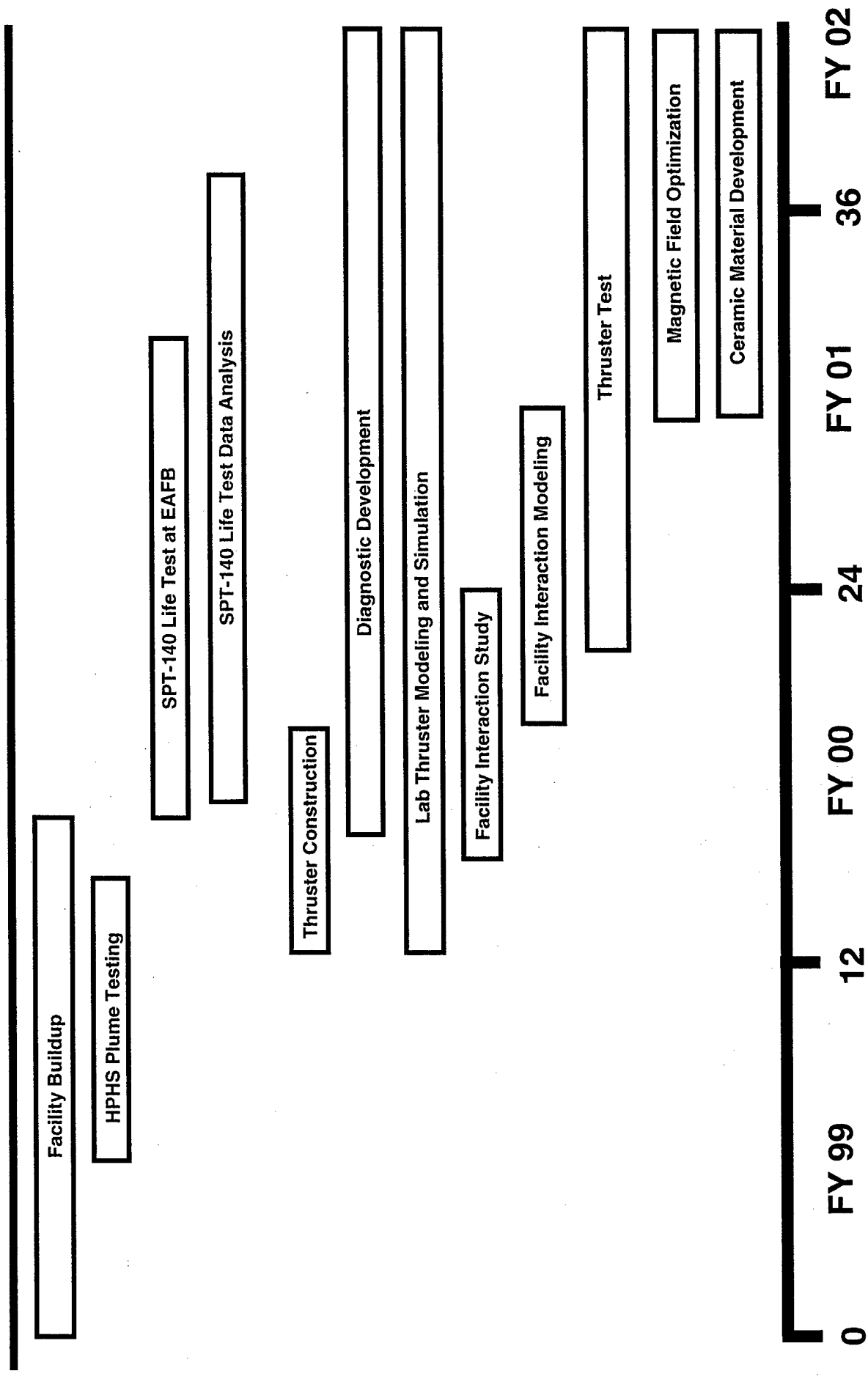
AFRL In-House Research



- **High Performance Hall System Program**
 - Space qualification of a 4.5 kW SPT-140 Hall thruster
 - AF Plume tests performed at NASA GRC, Univ. of Michigan
 - 7200 hour life test at AFRL starting March 2000
- **Advanced Hall Thruster Development Program**
 - Plasma diagnostic development
 - Construction of 5 kW laboratory thruster
 - Quantify thruster-facility interactions
 - Modeling and simulation
- **Research Collaborations**
 - AFOSR university research programs
 - Michigan
 - Stanford
 - Princeton
 - MIT



AFRL Electric Propulsion Road Map





AF Ground Testing for the 4.5 kW Hall Thruster

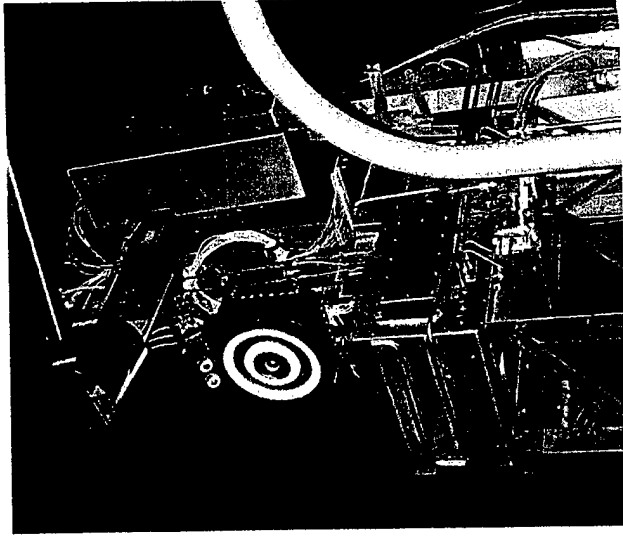


NASA - Glenn

Chamber #6

25' dia x 60' long

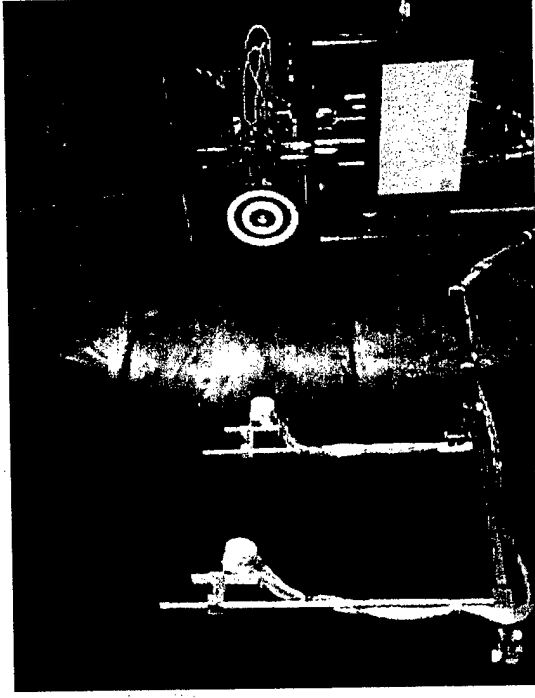
500,000 I/s on Xenon



University of Michigan

20' dia x 30' long

140,000 I/s on Xenon



AFRL - EP Lab

Chamber #3

10' dia x 20' long

350,000 I/s on Xenon



- Performance
- Current density
- EMI measurements
- Plume contamination

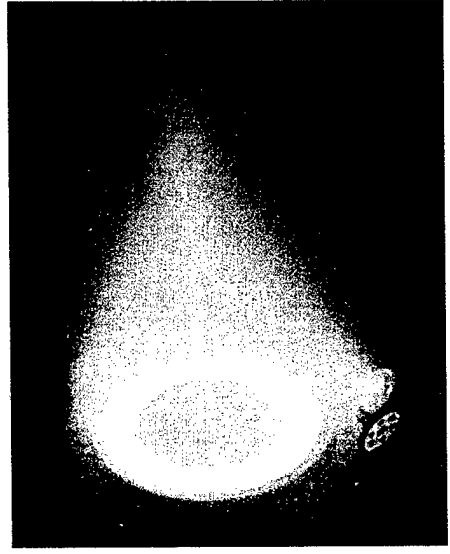
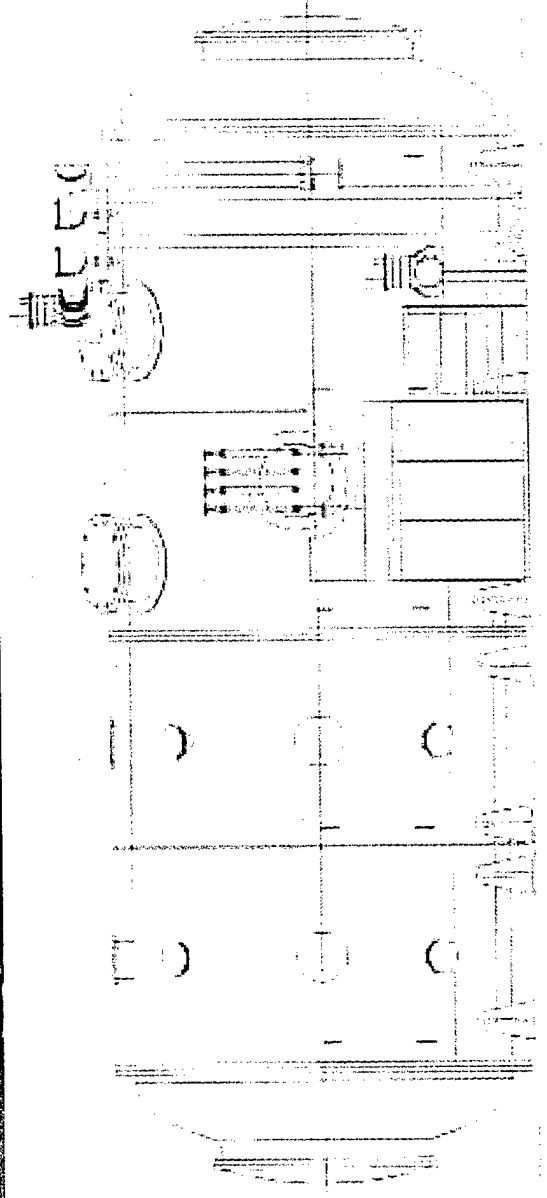
- Mass Spectrometry
- Current density
- Life Test (Performance)
 - 7200 Hours, 14 Months
- Plume Divergence
- Insulator Erosion Measurements



High Power Hall Thruster Life Test Vacuum Facility

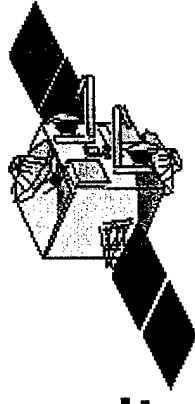


- 3 m diameter, 10 m length
- 350,000 l/s pumping speed (xenon)
- Construction complete Jan. 2000
- 7200 hour test begins March 2000, ends May 2001





4.5 kW Hall System Tech Transition Opportunity



MILSATCOM Advanced EHF

- Next Milstar system
- Approved extended duration orbit transfer
- Hall system supports NSSK and orbit raising
- #5 AF Space Command Near-Term Priority
- FY06 anticipated launch
- Aerospace Corp. SPT-140 evaluation

The Hall Thruster has a Technological Maturity sufficient to transition to commercial sector based on ground test data.

- Over 100 Russian flight thrusters decreases perceived risk

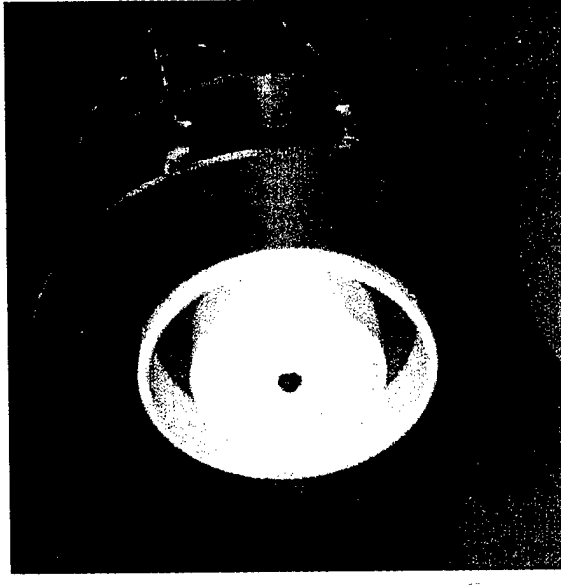


AFRL Advanced Hall Thruster Development



Laboratory Hall Thruster Development

- 5 kW laboratory Hall thruster with diagnostic access
- Jointly developed at AFRL with Univ. of Michigan
- Lower density improves survivability of probes
- Trend toward higher power thrusters
- Model thruster for other Laboratories / Institutions



Follow on Hall Thruster Development

- Magnetic field characterization and modeling
- Improved ceramic materials
- Improved power processing
- Alternate thruster geometries

Technical Challenges

- Thruster facility interactions
- Small thrusters poor diagnostic access

Approaches

- Construct model thruster
- Larger thruster



Hall Thruster Diagnostic Development

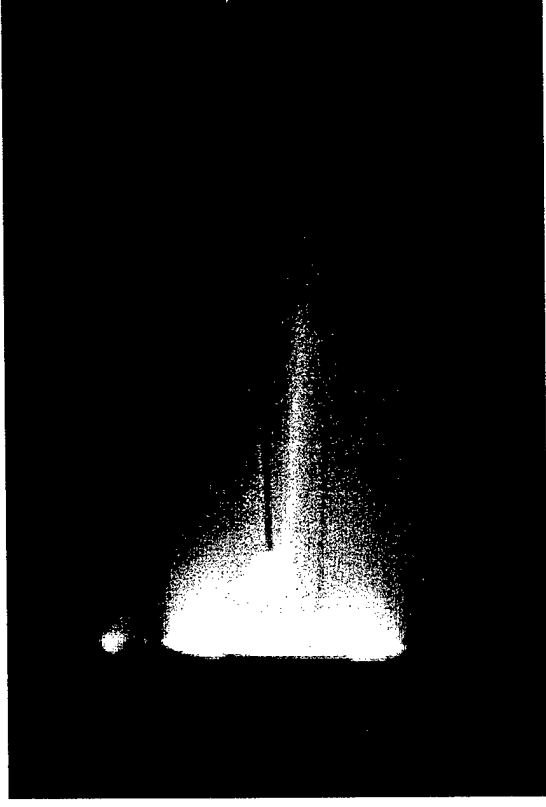


Electrostatic Probe Development

- Fast reciprocating probes
- Measurements
 - electron number density
 - electron temperature
 - plasma potential
 - electric field

Other Diagnostics

- Time of flight mass spectroscopy (TOFMS)
 - ion flux
 - ion energy
- High frequency microwave interferometry
 - electron number density
- Magnetic field characterization



Technical Challenges

- Probe ablation within thruster
- Perturbation of plasma parameters

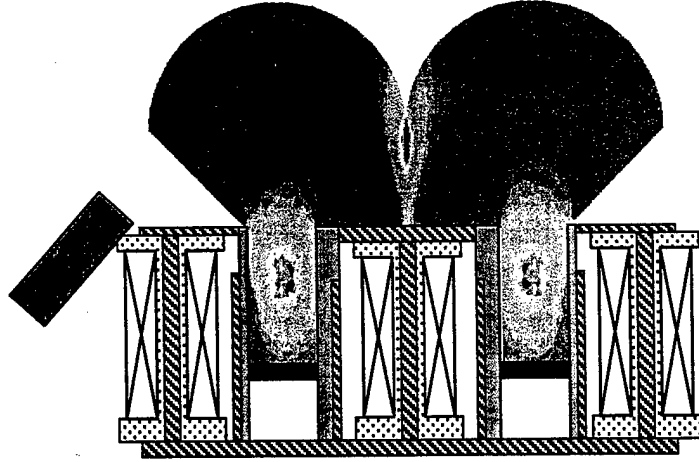
Approaches

- Construct fast reciprocating probe
- Larger thruster



Modeling and Simulation

Phase III Hall Thrusters: 30 kW to 60 kW for Orbit Transfer Missions
Critical Problem: Ground Test Facilities can dominate R&D costs (>\$20M)
Solution: Understand physics of background gas ingestion



2D Hybrid-PIC Hall Code
Plasma Density Contours

2-D Hybrid PIC Code

- Models Physics of Accel. Channel and Near-Plume



3-D PIC-DSMC Plume Code

- Comprehensive Model for Plume Dispersion and Effects

Team:

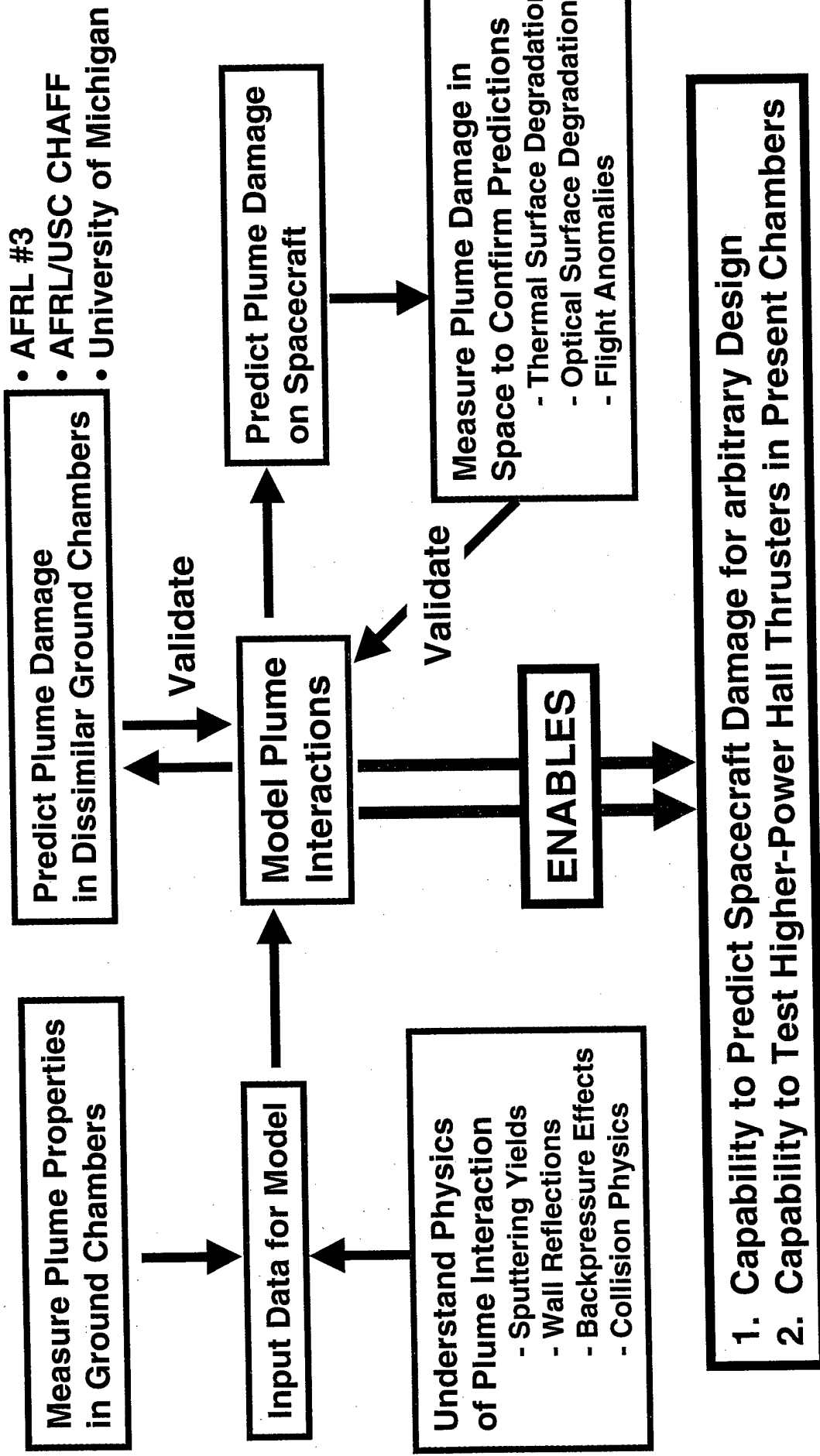
AFRL (AFOSR)
MIT (AFOSR)
LLNL (DOE)
Aerospace, AFRL/VS

4.5 kW Hall Lifetest Data, Modeling
Facility Interaction Theory & Modeling
Improvements to DSMC, PIC techniques
Xenon Collision Physics

Develop correction technique for backpressure at high propellant flow.
Test Higher Power Hall Thrusters in Existing Chambers



AF Modeling Needs for Electric Propulsion



Must balance COST vs. RISK REDUCTION at each step



Summary of Air Force Hall Thruster Development



- High Performance Hall System
 - Life test of SPT-140 for space qualification
 - Achieve Phase I goals (20% improvement)
 - Transition to customer
- Advanced Hall Thruster Development
 - Laboratory Hall thruster
 - Diagnostic development
 - Modeling and simulation
 - Achieve Phase II goals (35% improvement)
- Preparation for Phase III goals
 - Very high power laboratory Hall thruster development
 - Thruster-facility interaction
 - Increased modeling and simulation
- Collaboration with research institutions
 - AFOSR university research programs