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MEMORANDUM FOR PR (In-House Publication)

FROM: PROI (TI) (STINFO)

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 W

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

High Power
- P > 10 kW

Stationkeeping
- Orbit Transfer
- On-Orbit Servicing

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

Largely Commercial

Arcjets: Primex
Resistojets: TRW, Primex
Hall: ARC, Busek, Primex, TRW
Ion Thrusters: Hughes
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

AFOSR Research:
- U. Michigan
- MIT
- Princeton
- Stanford
- SBIRs

AFRL: ARC/ISTI
NASA: TRW
PAC (Busek - AFRL)

I_{tot} / M_{wet}

2000
Phase I

2005
Phase II

2010
Phase III

75% Increase

35% Increase

20% Increase

- High Power Operation (10+ kW)
- Testing Issues

Baseline: SPT-70

- Optimize Mag Fields
- Segmented Cathode
- Low-Erosion Materials
- Alternate Designs
- Transport Physics

- Improved PPU Design
- Optimize Engineering
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

<table>
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<th>FY 98</th>
<th>FY 99</th>
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<th>FY 01*</th>
<th>FY 02*</th>
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* Projected Budgets
** Program End Date

Funding Supports

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

Facility Buildup

HPHS Plume Testing

SPT-140 Life Test at EAFB

SPT-140 Life Test Data Analysis

Thruster Construction

Diagnostic Development

Lab Thruster Modeling and Simulation

Facility Interaction Study

Facility Interaction Modeling

Thruster Test

Magnetic Field Optimization

Ceramic Material Development

0  FY 99  12  FY 00  24  FY 01  36  FY 02
AF Ground Testing for the 4.5 kW Hall Thruster

NASA - Glenn
Chamber #6
25' dia x 60' long
500,000 l/s on Xenon

University of Michigan
20' dia x 30' long
140,000 l/s on Xenon

AFRL - EP Lab
Chamber #3
10' dia x 20' long
350,000 l/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

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

- Measure Plume Properties in Ground Chambers
- Predict Plume Damage in Dissimilar Ground Chambers
  - AFRL #3
  - AFRL/USC CHAFF
  - University of Michigan

Input Data for Model

Understand Physics of Plume Interaction
- Sputtering Yields
- Wall Reflections
- Backpressure Effects
- Collision Physics

Model Plume Interactions

ENABLES

Predict Plume Damage on Spacecraft

Measure Plume Damage in Space to Confirm Predictions
- Thermal Surface Degradation
- Optical Surface Degradation
- Flight Anomalies

1. Capability to Predict Spacecraft Damage for arbitrary Design
2. Capability to Test Higher-Power Hall Thrusters in Present Chambers

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