High-Power Electric Propulsion Laboratory

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Presentation Outline

1. Introduction to HPEPL
2. Chemical vs. Electrical Propulsion
3. Facilities
    a. Vacuum Test Facility 1
    b. Vacuum Test Facility 2
4. Operation of a Hall Effect Thruster
5. Research
    a. Thrusters
    b. Diagnostics
    c. Highlights

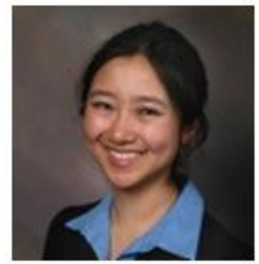
Introduction to HPEPL

High-Power Electric Propulsion Laboratory

Dr. Mitchell Walker
Lab Director

Nathan Brown
NSF Fellow

David Jovel
GEM Fellow
Aerospace Corp. Fellow



Connie Liu
NSF Fellow

Hisham Ali

Jean Luis Suazo B.
GEM fellow

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Nicholas Branch

David Gomez

Introduction to HPEPL

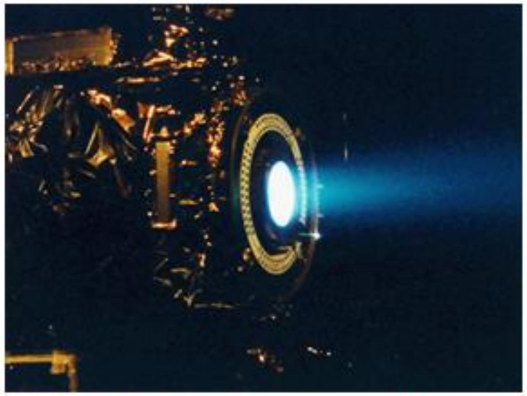
- High Power Electric Propulsion Laboratory (HPEPL) was founded in 2005 in Georgia Tech's Aerospace Engineering Department under the direction of Dr. Mitchell Walker
- Our mission: To further develop our understanding of plasma physics and advance the development of electric propulsion devices for future space applications
- Our research is aimed at:
  1. Increasing the performance and efficiency of high-power electric propulsion devices
  2. Identifying and determining possible steps towards mitigation of EP spacecraft integration issues
  3. Understanding the life limiting factors of EP devices
  4. Identifying non-propulsion applications of EP systems
     a) Space-plasma simulation
     b) Re-entry flow plasma simulation

Chemical vs. Electric Propulsion

Chemical Propulsion

Atlas V liftoff (Source: ULA)

Electric Propulsion



NSTAR ion engine (Source: NASA)

	Atlas V	NSTAR
Type	Liquid bipropellant rocket engine	Ion engine
Propellants	RP-1/LOX	Xenon
Thrust	3800 kN (>860,000 lbf)	92 mN (0.331 oz force)
I_{sp}	311.3 sec	3,100 sec
Purpose	Launch vehicle	Deep space travel
Advantages	• High thrust	• More payload capacity • Propellant chemical energy separate from thrust generation
Disadvantages	• Available energy limited to energy in chemical bonds	• Very low thrust • High power requirements (~kW)

Introduction to HPEPL

- Where does EP fit into the larger landscape of space systems architecture? Trades for the propulsion systems for spacecraft are driven by factors such as:
  1. Propellant and propulsion system mass vs. instrument payload mass
     a) Translates directly to dollars spent to get to space $$$$$$$$$
  2. Time of flight of mission vs. propellant mass (inverse relationship)
  3. Time of flight to desired orbits vs. propellant mass (inverse relationship)
  4. ”Burns” required for satellite orbit station keeping or nominal trajectory station keeping
  5. Satellite attitude agility—directly correlated to minimum requirements for pointing attitude maneuvers and instrument pointing slews

Introduction to HPEPL

- In the current landscape of facilitated access to space, both in terms of infrastructure and cost as well as the advent of small(er) satellite constellation architectures the viability of EP as the main propulsion system for these missions is increasing

- In order to support these missions, our lab is dedicated to the characterization of EP devices through direct measurement of performance characteristics as well as fundamental plasma physics research

Facilities: VTF-1

- ~ 14’ in diameter and 22’ long
- Base pressure on the order of 1x10-7 torr
- Equipped with 6 diffusion pumps and 2 mech-pump turb-pump sets.
- Can handle toxic propellants and has been used for testing arcjets, RF thrusters and Hall thrusters. High pumping speeds allow for testing of thrusters with large mass expenditures
- System reaches high vacuum in 2 movements. The first leverages the double mech pump turbo pump system to bring the system to a pressure on the order of a few millitorr.

- The second movement leverages the 6 diffusion pumps in tandem with the mech pump-turbo pumps. The diffusion pumps use what is essentially a boiling oil and . The boiling oil is compressed through vertically tapering hollow cones and escapes through the sides. Once the oil vapor escapes through the side, the jet streams collide with other gas molecules in the cavity of the diffusion pumps and the cool walls of the diffusion pumps creating a pressure gradient. The mech-turbo pumps suck out then suck out the gas molecules.

- Supported testing operations for industry partners such as Lockheed-Martin and Moog
- Supported critical EP development led by Defense Advanced Research Projects Agency (DARPA)

Facilities: VTF-2

- ~ 16’ in diameter by 22’ long
- Can reach base pressure on the order of 2x10-9 torr
- Equipped with 10 LN2 shrouds connected to a recirculating LN2 system and 10 liquid helium scroll compressors.
- System reaches high vacuum in 2 major movements. The first movement employs mech-pump and turbo-pump to reach vacuum on the order of a few tens of millitorr

Facilities: VTF-2

- The second movement utilizes the the recirculating nitrogen system to reach high vacuum on the order of 2x10-9 torr.
  - Cryo compressors and LN2 pump to pump LN2 and compress GN2
  - LN2 shrouds to act as a cold surface to trap the free particles
  - Scroll compressors circulate LHe in an inner shroud to trap lower heavier particles

Hall Effect Thruster (HET)

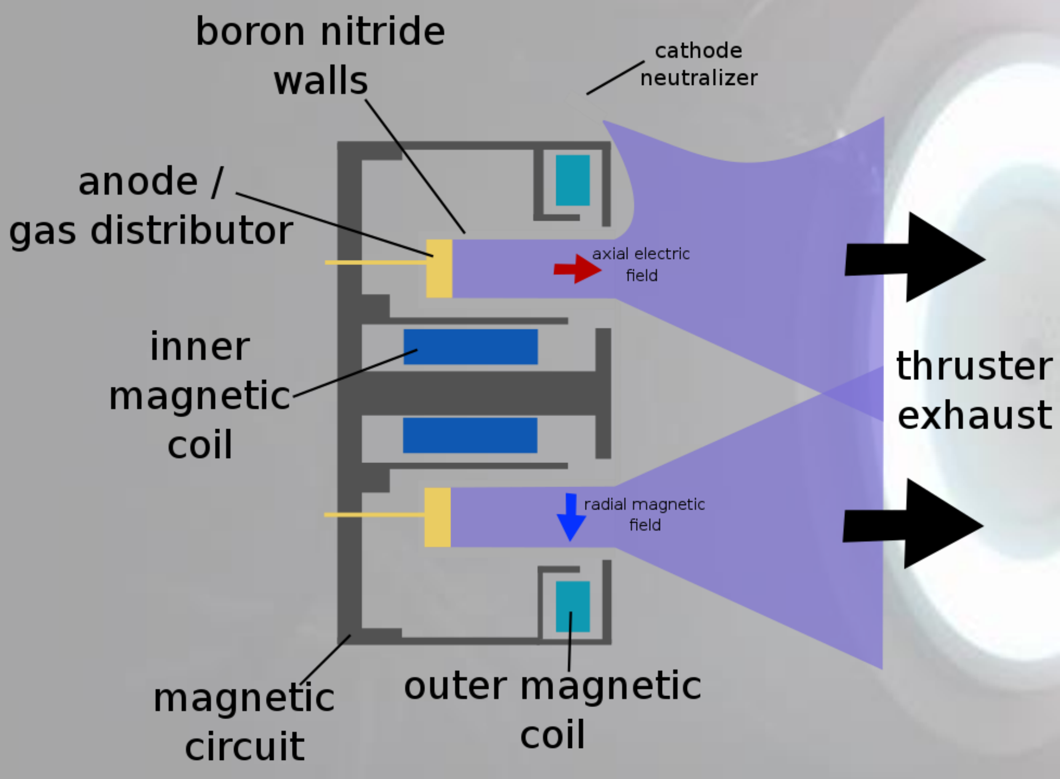
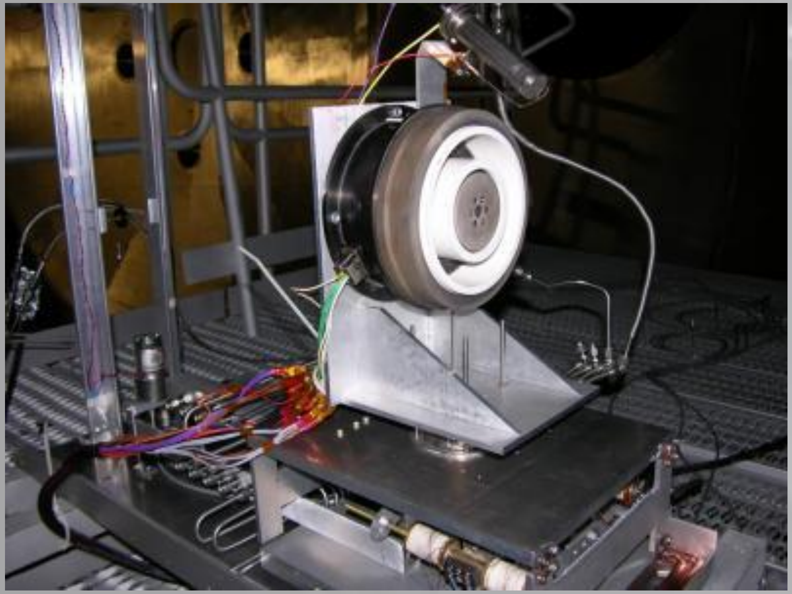


Image Credit: David Staack, Texas A&M University

- Used for a variety of space mission applications
- Ions are created and accelerated in an electric field
- Knobs:
  B-field strength,
  flow rate,
  propellant,
  geometry,
  discharge voltage
  (applied potential)

Research: Thrusters

- HPEPL tests a wide range of HETs
  - Smallsat (T-40): 200 W, 14 mN, 1275 s Isp
  - High-power (T-220): 20 kW, 1.0 N, 2500 s Isp



T-140 HET test setup

T-140 HET operating on Xenon

Research: Diagnostics

- Motivation
  - EP ion plumes exhibit many high-frequency plasma oscillations
  - Non-intrusive, time-resolved diagnostics are needed to understand short timescale plume dynamics

- Parameters of Interest:
  - Ionization fraction
  - Plasma temperature
  - Ion velocity
  - Electrical conductivity
  - Particle diffusion
  - Instabilities

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Research: Diagnostics, cont.

- Plasma Diagnostic Probes
  - Langmuir
    - measures electron temperature, ion and electron number densities, and plasma potential
  - Faraday
    - measures plasma ion current, often using angular sweeps across plume
  - ExB
    - determines ion charge population
  - Retarding Potential Analyzer (RPA)
    - measures ion energy distribution in thruster plume

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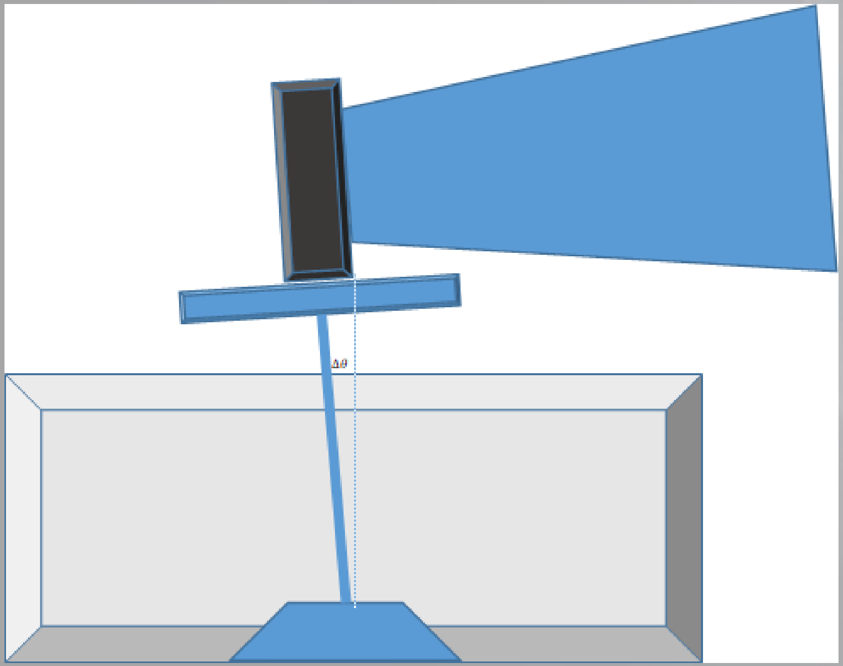
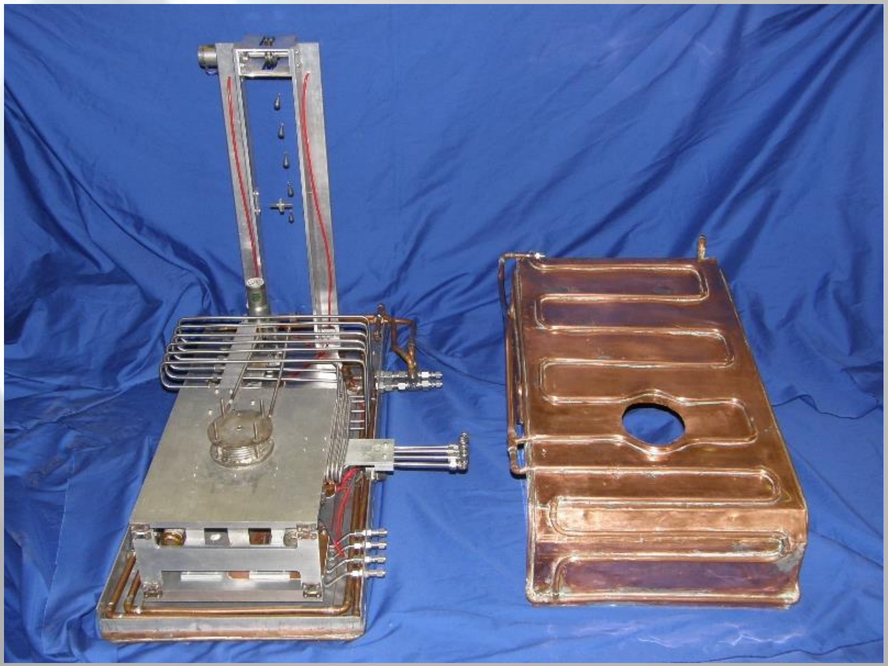
Research: Diagnostics, cont.

- Null-Type Inverted Pendulum Thrust Stand
  - Measures thrust over a range of 1 mN - 5 N
  - Inverted pendulum increases sensitivity
  - Null-type feature eliminates thrust alignment error caused by thrust deflection





Inverted Pendulum Thrust Stand

Research: Diagnostics, cont.

- Terahertz Time-Domain Spectroscopy System (THz-TDS)
  - Records phase shifts caused by electrons to quickly, non-intrusively measure electron number density in plasma plumes
- Thomson Scattering System
  - Utilizes scattering of electromagnetic radiation by free electrons in plasma to yield time-averaged measurements of electron temperature and number density
    - Spatial resolutions <500 µm

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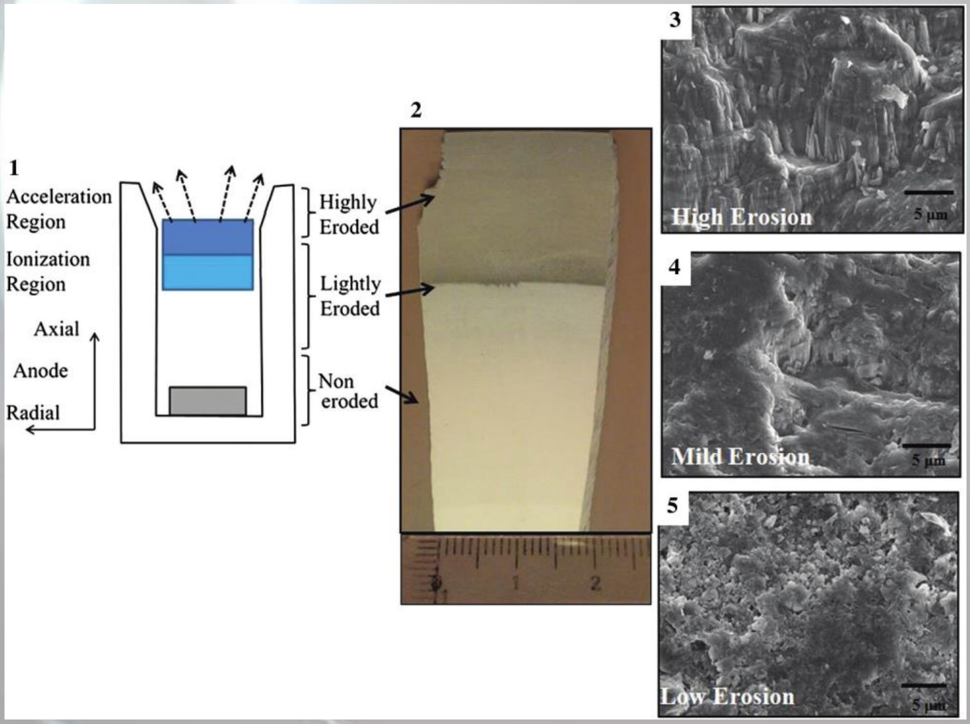
Research: Highlights

- Facility Effects on HET performance
  - Pressure
    - How do chamber design and operating conditions impact measured thruster performance data?
  - Electrical
    - How does chamber conductivity affect the HET electrical circuit?
- Thermal Analysis of HETs
  - How is thruster performance affected by heating of the HET channel walls during operation?

Research: Highlights, cont.

- High-Speed Pulsed Plasma
  - Create and sustain rapidly-pulsed plasma to study the physics of fast plasma generation and quenching
- Erosion of HET Channel Walls
  - How do the channel wall surface features change under plasma erosion?



Questions?