A Facility Effect Characterization Test of the BHT-6000 Hall Thruster

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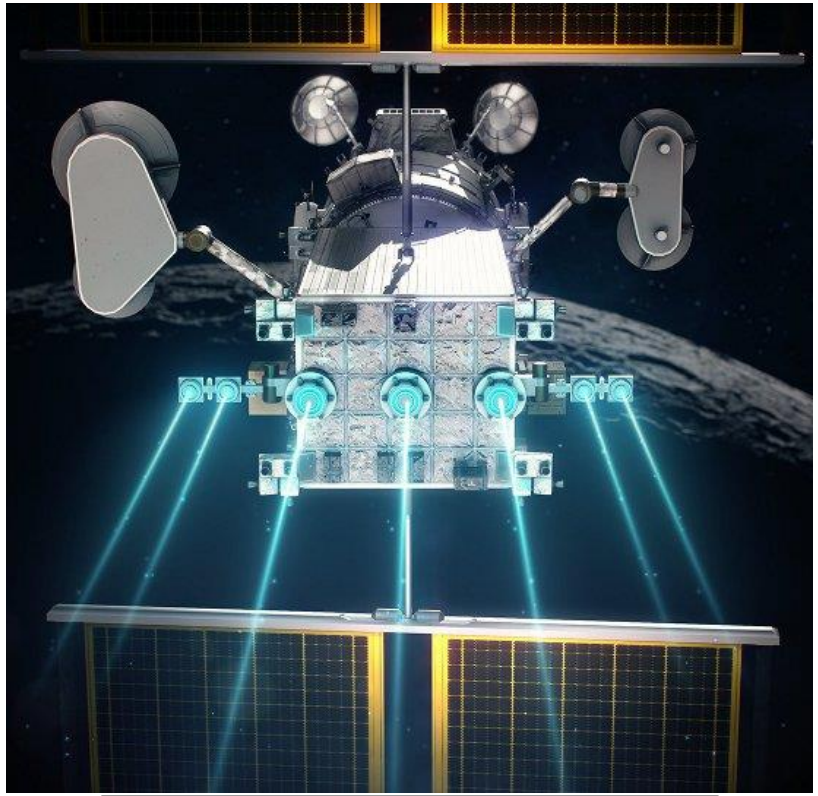
Introduction

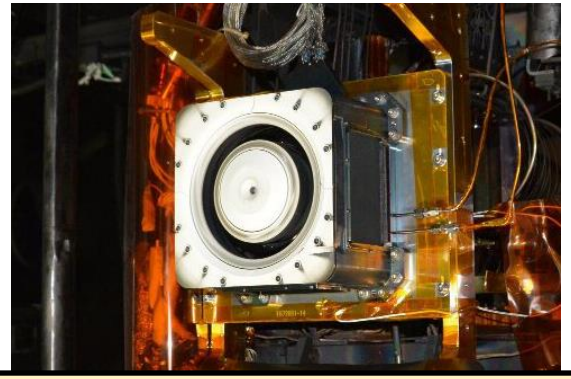
- Under the Artemis program, NASA is building a Moon-orbiting outpost called Gateway
- The first two elements of Gateway are the Power and Propulsion Element (PPE) and the Habitations and Logistics Outpost (HALO), which are launched together as the co-manifested vehicle (CMV)
- NASA is partnering with Maxar Technologies to build the PPE
- PPE utilize a 48-kW EP system that includes three 12-kW and four 6-kW Hall thrusters
- The 6-kW Hall thrusters are BHT-6000s, supplied by the Busek Company, Inc.
- As a part of engineering development, a facility effect test was performed to aid in the prediction of in-flight behavior
  - Background pressure test: Varied background pressure by injecting propellant in the far-field
  - Electrical environment test: Varied the electrical environment by biasing the beam dump



Render of Co-Manifested Vehicle

Test Article

- The test article is a BHT-6000 Hall thruster engineering unit
  - Developed from the BHT-5000 described in a prior publication (IEPC 2019-492)
  - Designed for low erosion using Busek discharge channel wear model
  - Centrally mounted barium oxide cathode
- At the time of this test, shape of the ceramic discharge channel mimicked ~3000 hours of wear based on model prediction
  - Test duration was ~100 hours, no significant change to shape
- Table of operating point shown on the lower right
  - Background pressure test was performed at all OPs, electrical environment test was performed at OP1, OP4, OP5, and OP8

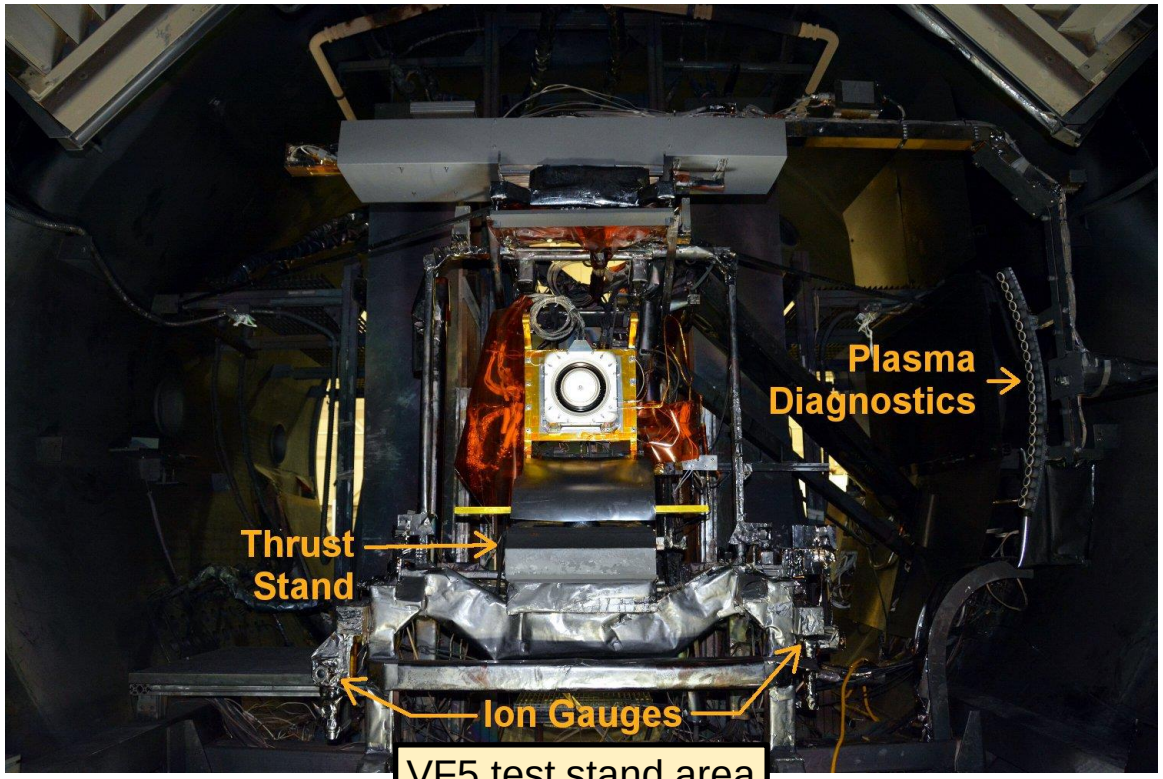


BHT-6000 engineering unit on test stand

Operating Point	Discharge Voltage, V	Discharge Power, kW
OP1	300	3
OP2	300	4
OP3	300	4.5
OP4	300	5
OP5	600	3
OP6	600	4
OP7	600	5
OP8	600	6

Test Facility

- Testing was performed in NASA GRC VF5
  - Background pressure was tracked with ion gauges located ~1 m from the thruster slightly upstream of the thruster exit plane
  - Beam dump biased with respect to facility ground and is isolated from the chamber wall



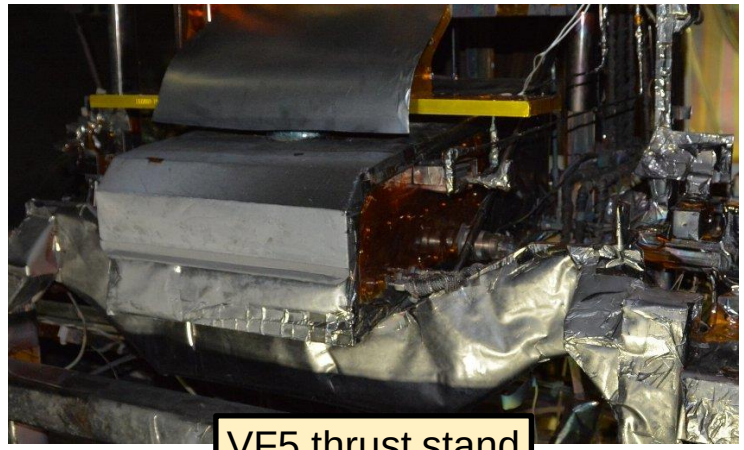
VF5 test stand area

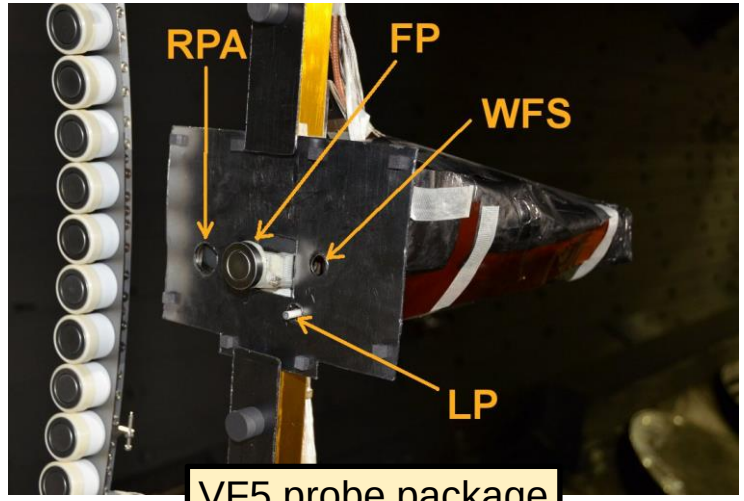

VF5 beam dump

Diagnostics

- Inverted pendulum thrust stand
  - Constantly monitored
- Probe package:
  - Faraday Probe (FP), also used as a Guarded Langmuir Probe (GLP)
  - Langmuir probe (LP)
  - Four-grid retarding potential analyzer (RPA)
  - Wien filter spectrometer (WFS)

Plasma Diagnostics	Background Pressure Test	Electrical Environment Test
FP	5 distances, -110º to 110º, continuous	1 and 1.5 m, -110º to 110º, continuous
GLP/LP	1.5 m, -105º to 105º, 5º interval, except within ±30º where interval is 15º	Same as left plus a small subset at 1 m
RPA	Same as GLP/LP	Not used
WFS	-105º to 105º, 15º interval	Not used


VF5 thrust stand



VF5 probe package

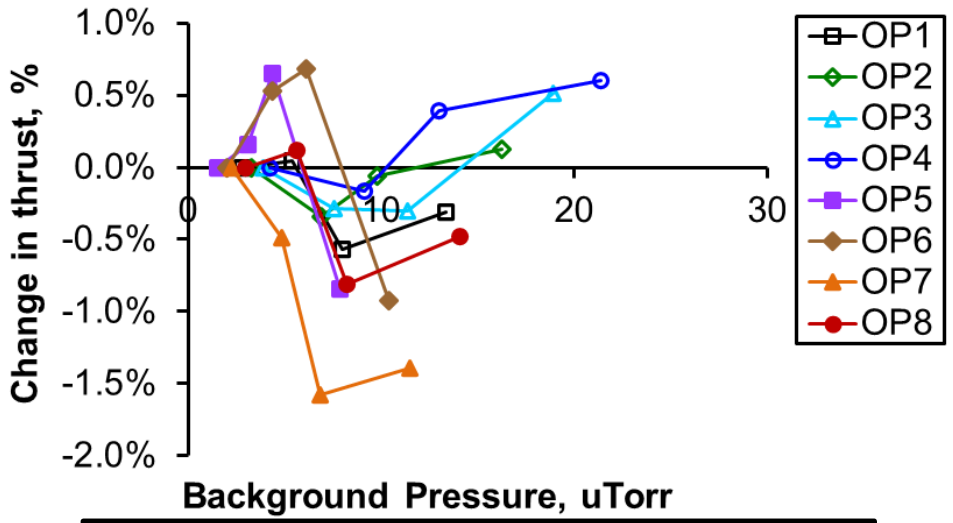
Thruster Performance

- Established baseline performance of the thruster
  - Recall thruster channel has a shape mimicking ~3000 hours of wear
  - Six runs at each operating point, spread out over six weeks; each run start and end with zero-thrust measurement
  - Results below are average of six runs each
  - Thrust was corrected for discharge power, and flow rate (for calculating specific impulse) was corrected for discharge current

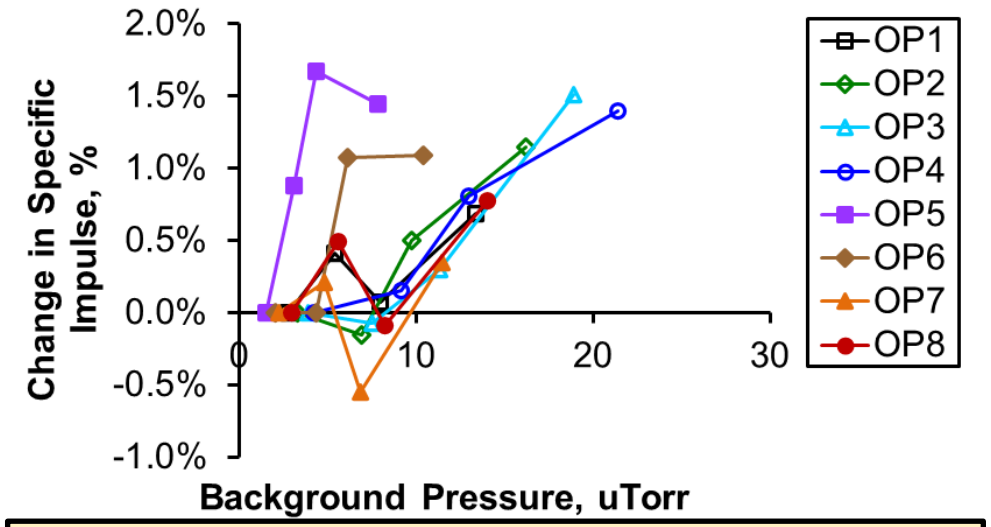
Operating Point	Discharge Voltage, V	Discharge Power, kW	Background pressure, uT	Avg. thrust, ± 3-σ uncertainty, mN	Avg. specific impulse, ± 3-σ uncertainty, s
OP1	300	3	2.7	191.4 ± 2.4	1794 ± 37
OP2	300	4	3.4	249.5 ± 2.2	1855 ± 35
OP3	300	4.5	3.8	276.6 ± 2.4	1878 ± 34
OP4	300	5	4.1	302.4 ± 2.4	1898 ± 36
OP5	600	3	1.5	133.8 ± 4.1	2176 ± 57
OP6	600	4	1.9	181.9 ± 4.1	2271 ± 48
OP7	600	5	2.4	228.9 ± 4.2	2354 ± 43
OP8	600	6	2.8	285.7 ± 4.4	2485 ± 53

Background Pressure Test: Performance Trends

- Test performed at 1x, 2x, 3x, and 5x lowest achievable background pressure for each operating point, in order
  - Mass flow adjusted to maintain fixed discharge current
- Measured change in thrust was on the order of or less than the measurement uncertainties
- The increase in specific impulse with background pressure was likely due to ingestion of background neutrals



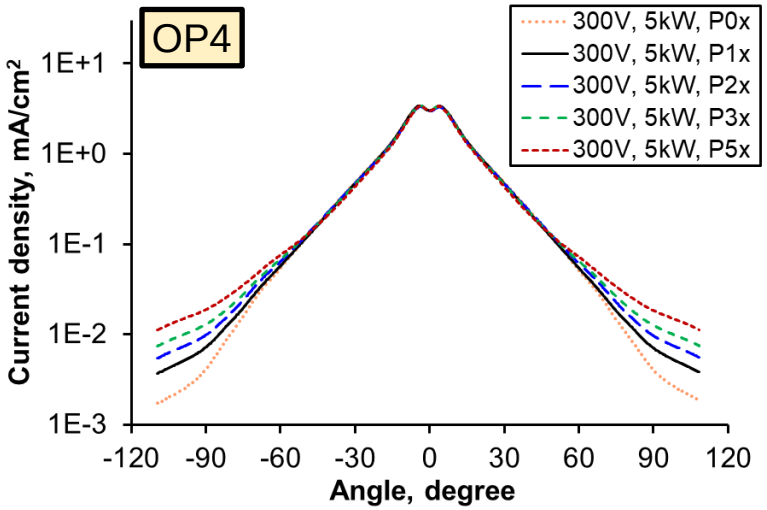
Change in thrust with background pressure

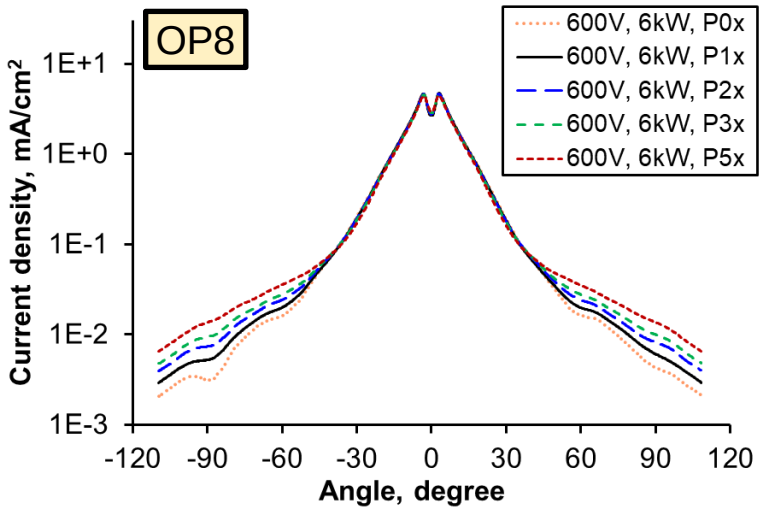


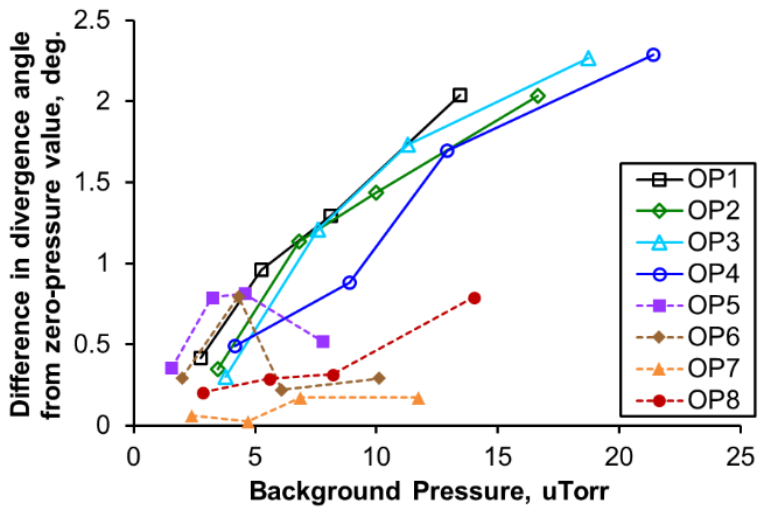
Change in specific impulse with background pressure

Background Pressure Test: Plume Profile

- Ion current density profiles at 1 m plotted below
  - "P0x" is the zero-pressure profiles extrapolated from other pressures by performing linear fit at each polar angle
  - No significant change inside of 45º from the firing axis; decrease in densities beyond 45º, likely associated with charge exchange actions between the main beam and background neutrals
  - With decreasing background pressure, distinct structures in the profile at high angles can be seen (~70º and ~95º for 600 V, 6 kW operations)
    - Possible relation to side plume populations seen in magnetically-shielded Hall thrusters
- Divergence angle generally decreased with increasing background pressure
  - Note that plot at lower right shows magnitude of the change in divergence angle (i.e., the value is always positive)

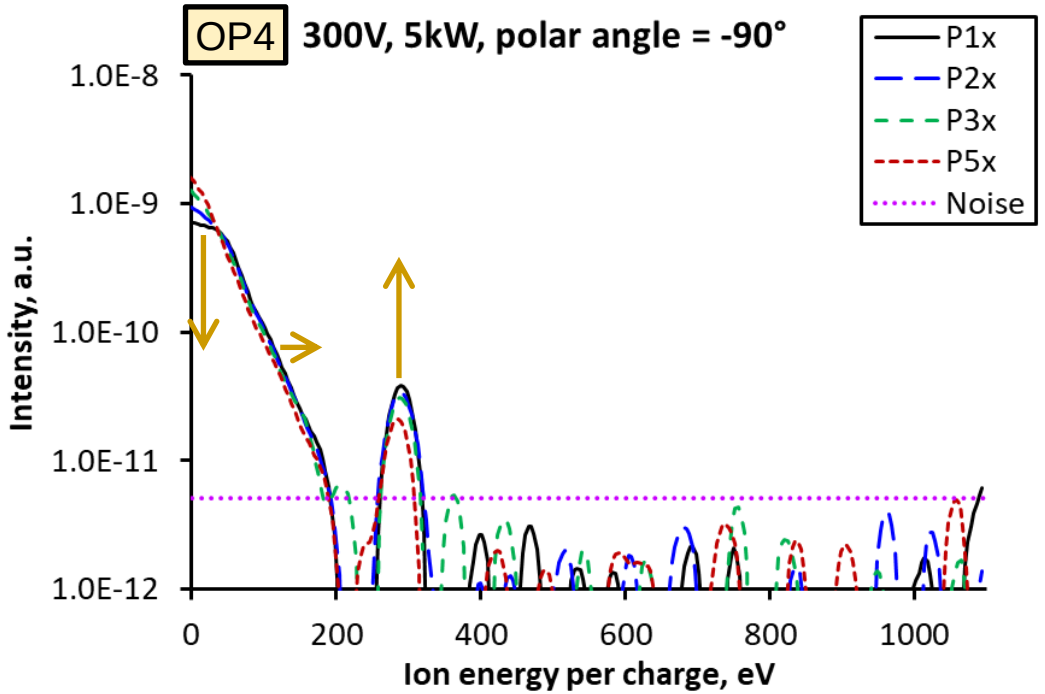


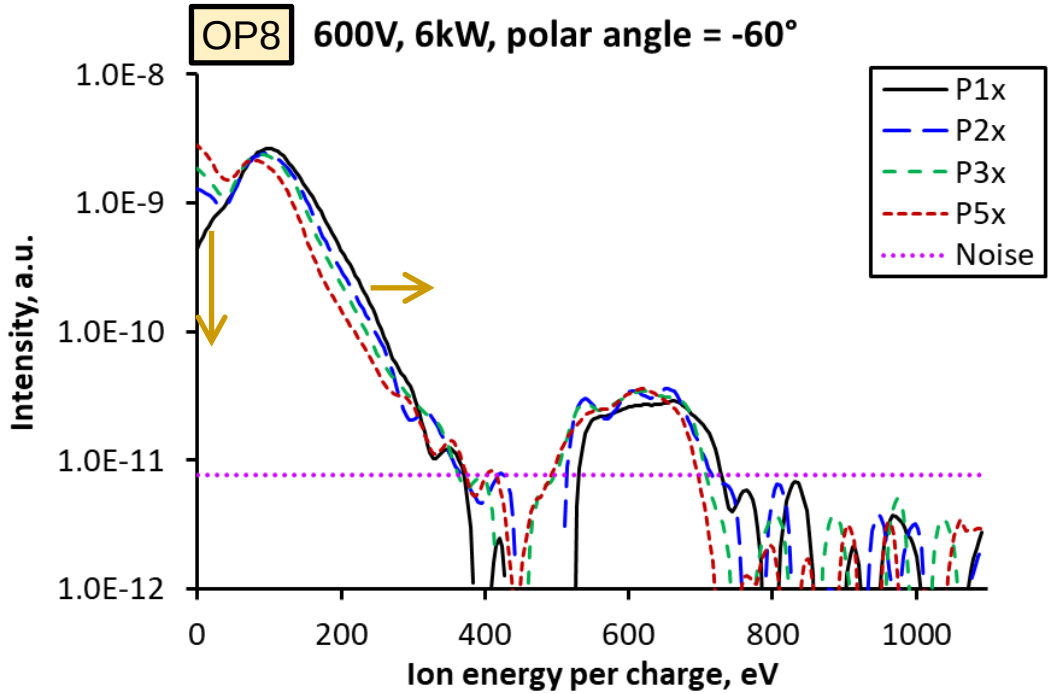




Background Pressure Test: Ion Energy Distribution

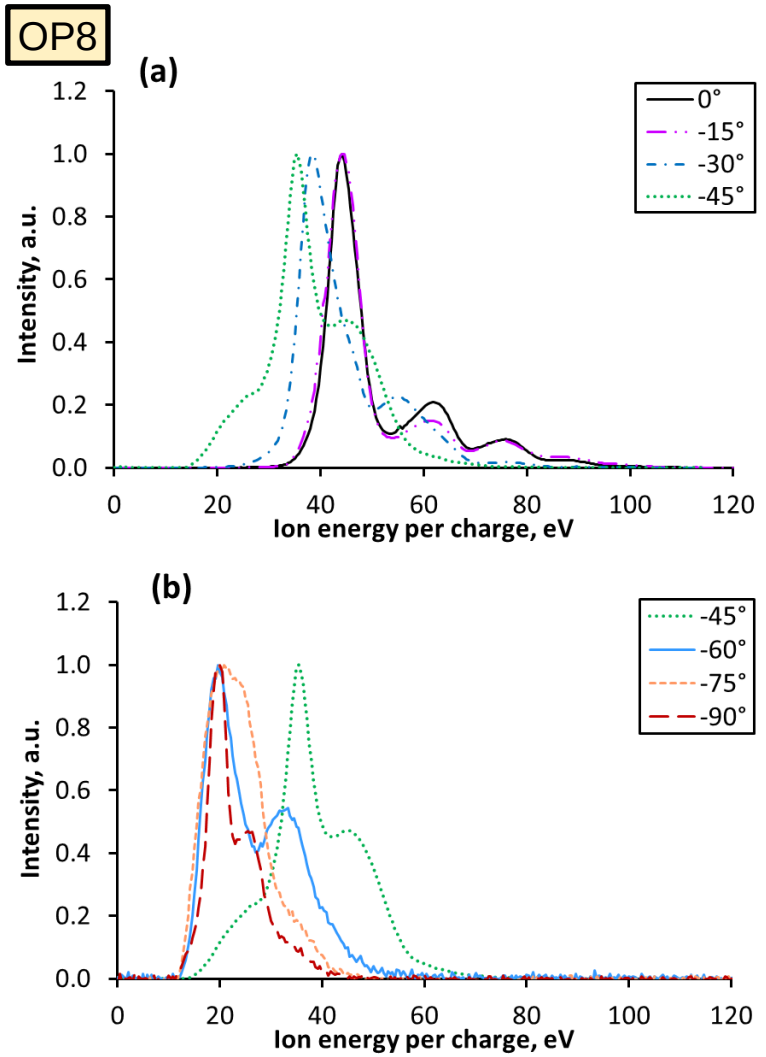
- Ion energy distribution
  - Averaged energy of beam ions was constant over tested background pressure
  - Densities of beam ions and properties of other ion species varied with background pressure
  - Arrows indicate trends with decreasing background pressure
  - The “Noise” floor is calculated as 3-σ of the data points at >800 V in RPA bias voltage





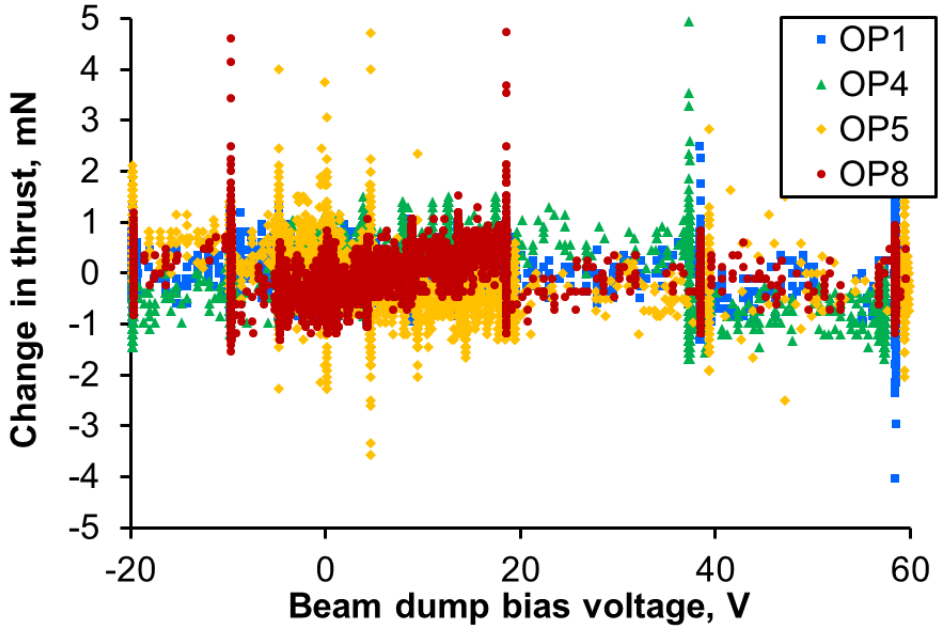
Background Pressure Test: Multiply-Charged Species

- For the main beam, multiply-charged ion current fractions varied by a few percent across background pressure, which is on the order of the measurement uncertainty
  - Doubly-charged current fraction was 0.15 to 0.27 depending on operating point while triply-charged fraction was up to 0.11
  - Quantity of multiply-charged species tend to be higher for operations at higher discharge power
  - See paper for detailed data
- Wien-filter scans of the side plume showed large amount of overlap between different ion populations making analysis difficult
  - Signs of multiple populations with different ion energy present (as seen in the RPA data)
  - Populations with lower than beam energy tend to have broader width

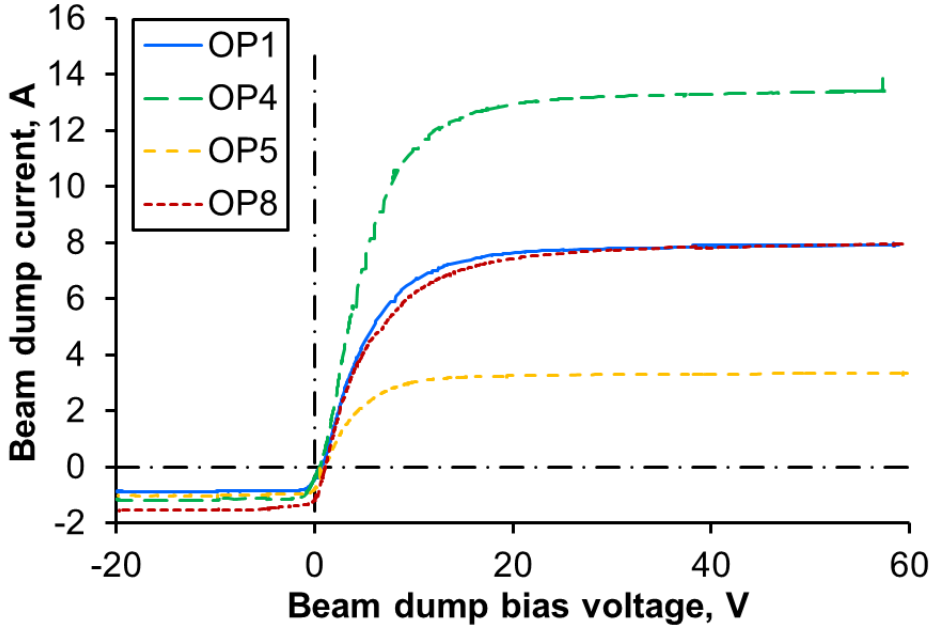


Electrical Environment Test: Performance Trends

- Beam dump was biased with respect to facility ground
  - Up ramp: -20, -10, 5, 0, 5, 10, 15, 20, 40, and 60 V; dwelled for 5 minutes at each step
  - Down ramp: 60, 20, -5, -20 V; enough time to take probe data at each step (15-20 minutes)
- Change in thrust was negligible with change in beam dump bias voltage
- Change in beam dump current with bias voltage resembles Langmuir probe traces
  - OP1 and OP8 has the same discharge current but OP8 exhibit more current in ion saturation due to lower divergence



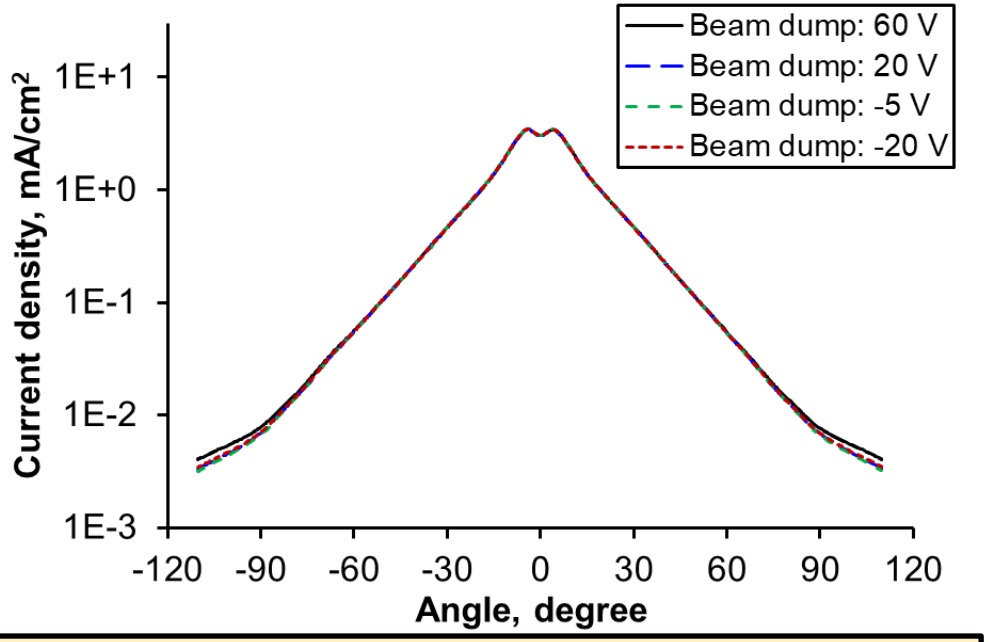
Change in thrust with beam dump bias voltage



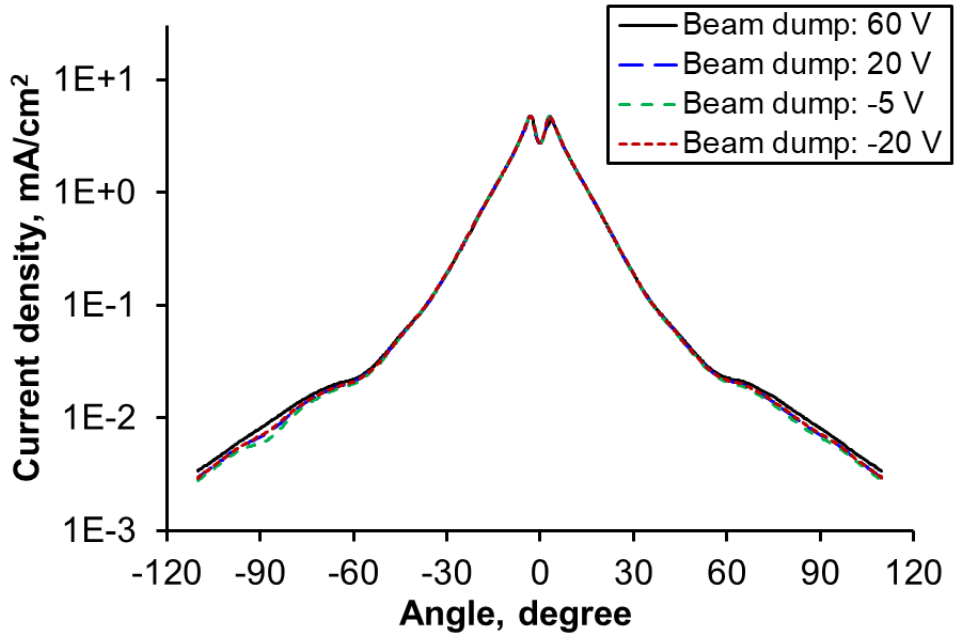
Change in beam dump current with bias voltage

Electrical Environment Test: Plume Profile

- Ion current density profiles were identical to within measurement uncertainty over the range of tested beam dump biases
  - Measurements shown below were taken at 1 m



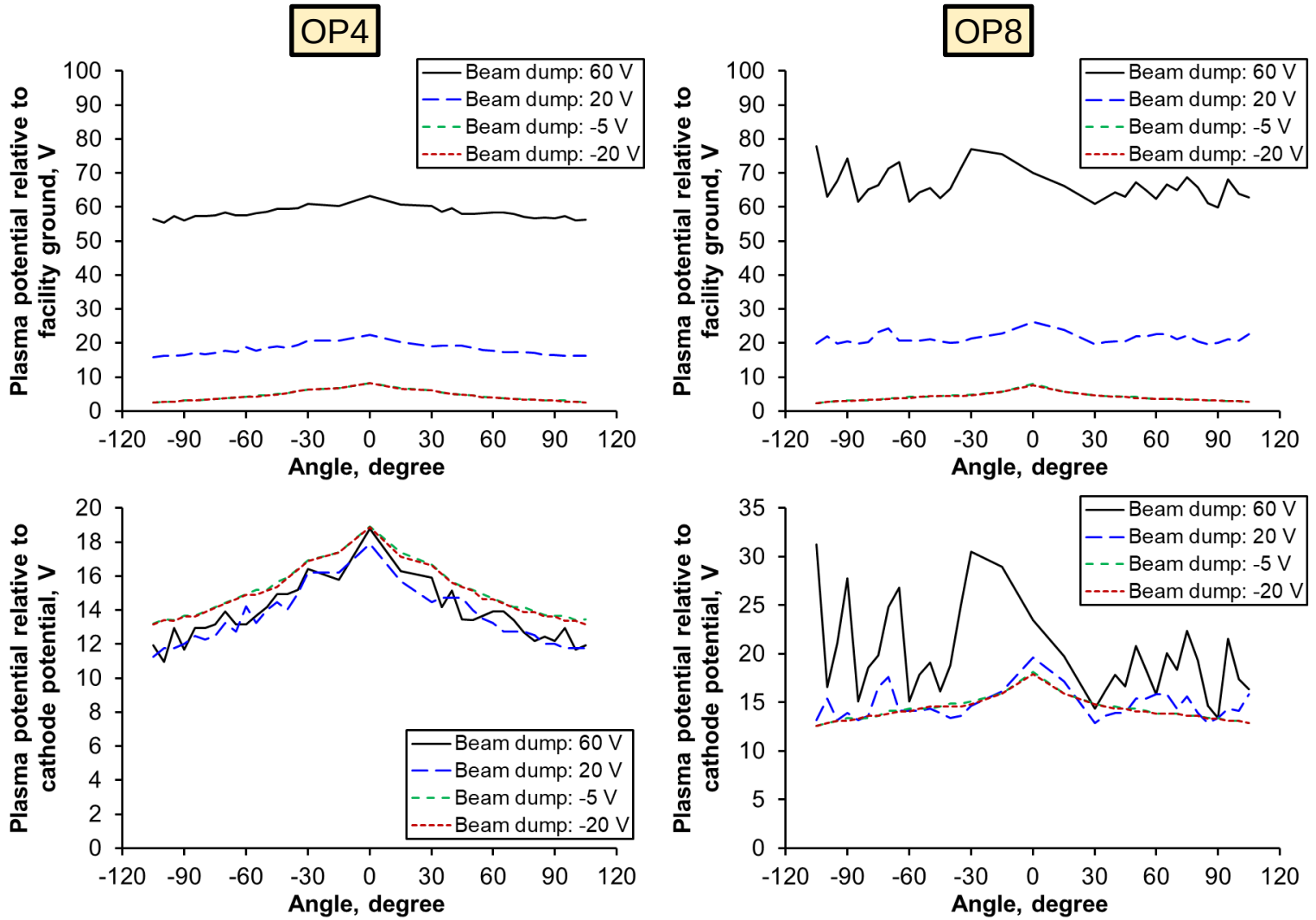
Ion current density at various beam dump bias for OP4



Ion current density at various beam dump bias for OP8

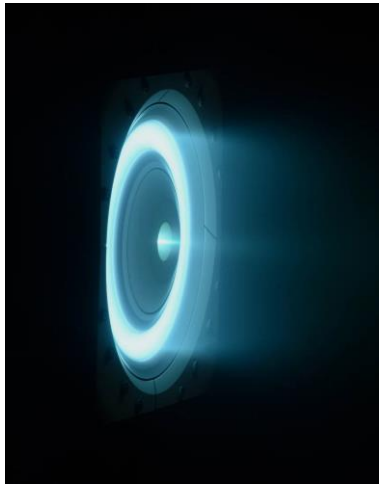
Electrical Environment Test: Plasma Potential

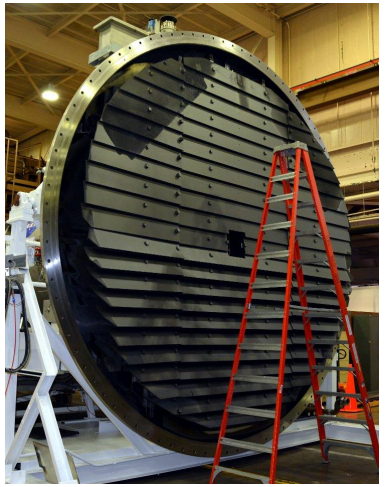
- Plasma potential with respect to facility ground and appeared to increase with bias voltage (top two plots)
- By subtracting out cathode potential, one can see the plasma potential relative to cathode potential does not vary within the range of tested bias voltage (bottom two plots)
  - Data at OP8 with 60 V beam dump bias were particularly noisy



Summary

- Facility effect test of the BHT-6000 in VF5 was completed; from the background pressure test:
  - Thrust was constant to within measurement uncertainty over the tested range of pressures (up to 5x lowest achievable)
  - Specific impulse increased slightly (1 to 1.5%) with increasing pressure
  - Excepting quantities like the energy of beam ions, accurate predictions of most plume properties for flight can only be made using measurements taken at <10 uTorr and often required extrapolation from measurements at multiple background pressures
- From the electrical environment test
  - Performance and plume measurements were identical over the tested range of beam dump biases





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Questions?