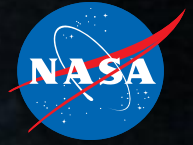




Plasma Potential and Langmuir Probe Measurements in the Near-field Plume of the NASA-457Mv2 Hall Thruster

Abstract: In order to further the design of future high-power Hall thrusters and provide experimental validation for ongoing modeling efforts, plasma potential and Langmuir probe measurements were performed on the 50-kW NASA-457Mv2. An electrostatic probe array comprised of a near-field Faraday probe, single Langmuir probe, and emissive probe was used to interrogate the near-field plume from approximately 0.1 – 2.0 mean thruster diameters downstream of the thruster exit plane at the following operating conditions: 300 V, 400 V and 500 V at 30 kW and 500 V at 50 kW. Results have shown that the acceleration zone is limited to within 0.4 mean thruster diameters of the exit plane while the high-temperature region is limited to 0.25 mean thruster diameters from the exit plane at all four operating conditions. Maximum plasma potentials in the near-field at 300 and 400 V were approximately 50 V with respect to cathode potential, while maximum electron temperatures varied from 24 – 32 eV, depending on operating condition. Isothermal lines at all operating conditions were found to strongly resemble the magnetic field topology in the high-temperature regions. This distribution was found to create regions of high temperature and low density near the magnetic poles, indicating strong, thick sheath formation along these surfaces. The data taken from this study are considered valuable for future design as well as modeling validation.



Plasma Potential and Langmuir Probe Measurements in the Near-field Plume of the NASA-457Mv2 Hall Thruster

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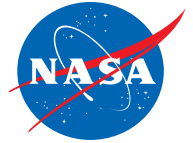
NASA Glenn Research Center, Cleveland, OH, 44135

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Presentation Outline

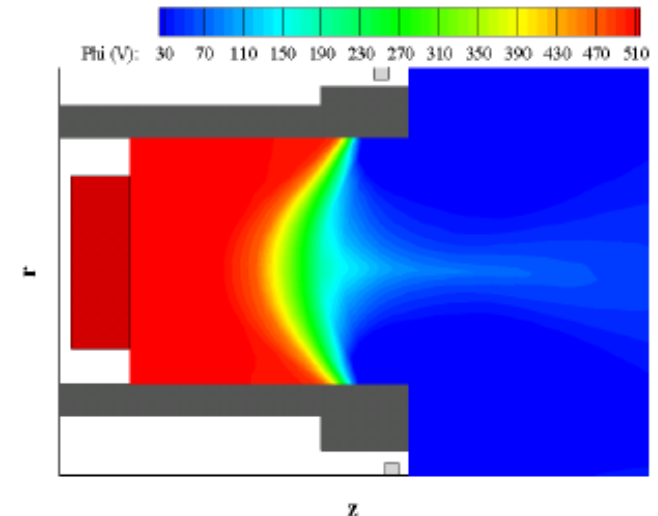
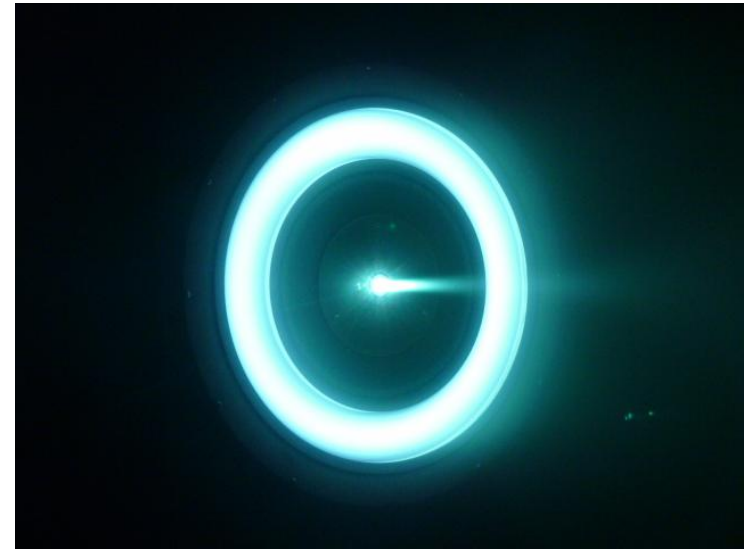


- Background and motivation
- Experimental setup
 - Test article – the NASA-457Mv2
 - Electrostatic probe setup
- Test results – Contours of plasma potential and electron temperature
- Discussion of results
 - Isothermal line structure
 - Effects of isothermal lines on plasma near magnetic pole surfaces
 - Analysis of the acceleration zone/high-temperature regions
 - Comparison of clocked positions for azimuthal symmetry
- Conclusions

Background and Motivation



- There has been an increased interest in high-power Hall thrusters in the vicinity of 20-50 kW
- The 50-kW NASA-457Mv2, designed and built at GRC, is an attractive option for studies on high-power Hall thrusters
 - Characterize performance/efficiency for future designs
 - Provide baseline data on an existing test article for comparison to future design involving magnetic shielding for long lifetimes
 - Provide experimental data for validation of ongoing modeling efforts at JPL/GRC using Hall2De
- Part of this effort is electrostatic probe measurements taken in the near-field plume



*Simulation image taken from Mikellides, I. G., Katz, I., Kamhawi, H., and Vannoord, J. L., "Numerical Simulations of a 20-kW Class Hall Thruster Using the Magnetic-Field-Aligned -Mesh Code Hall2De," Presented at the 32nd International Electric Propulsion Conference, IEPC-2011-244, Wiesbaden, Germany, September 11-15, 2011.

Experimental Setup – NASA-457Mv2

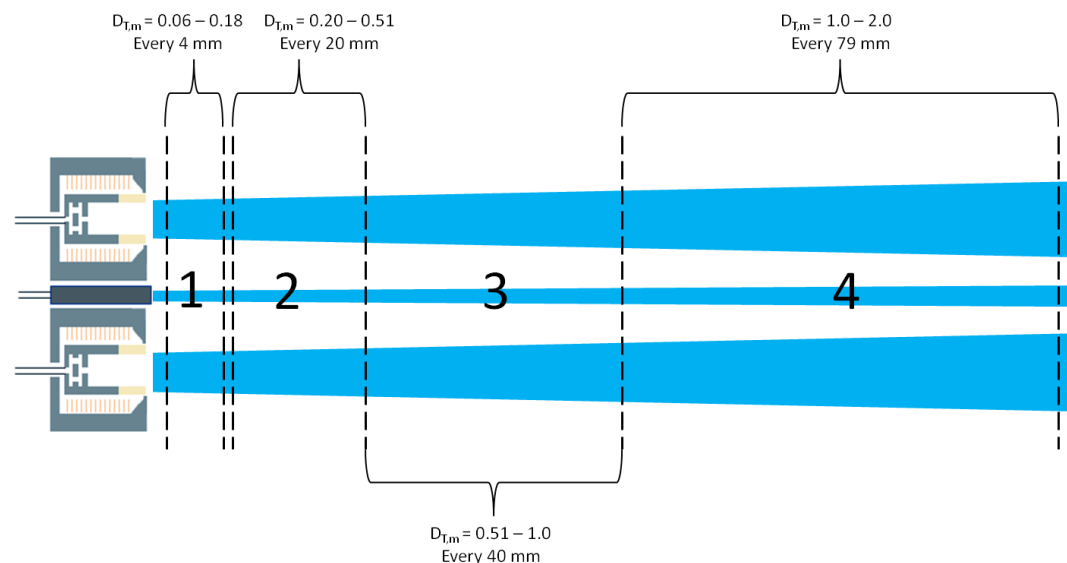
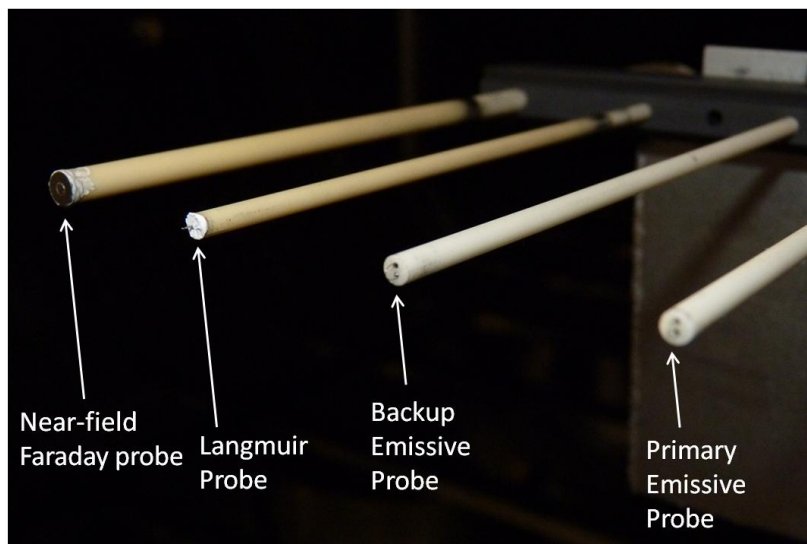


- Test article is the 50-kW NASA-457Mv2 Hall thruster, a higher fidelity model based on lessons learned from the earlier NASA-457M – typically operated up to 500 V and 100 A
- Thruster was placed in the main volume of Vacuum Facility 5 at GRC
- Commercial power supplies were used to sustain the discharge and provide power to the magnets and cathode keeper/heater
- Center-mounted cathode was made flush with the thruster exit plane to facilitate near-field measurements
- Symmetric magnetic field topology used with the strength chosen to maximize anode efficiency as determined by a thrust stand

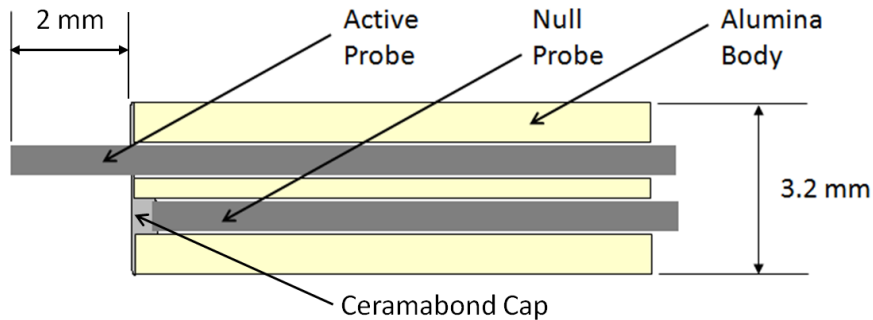


Electrostatic Probe Setup - General

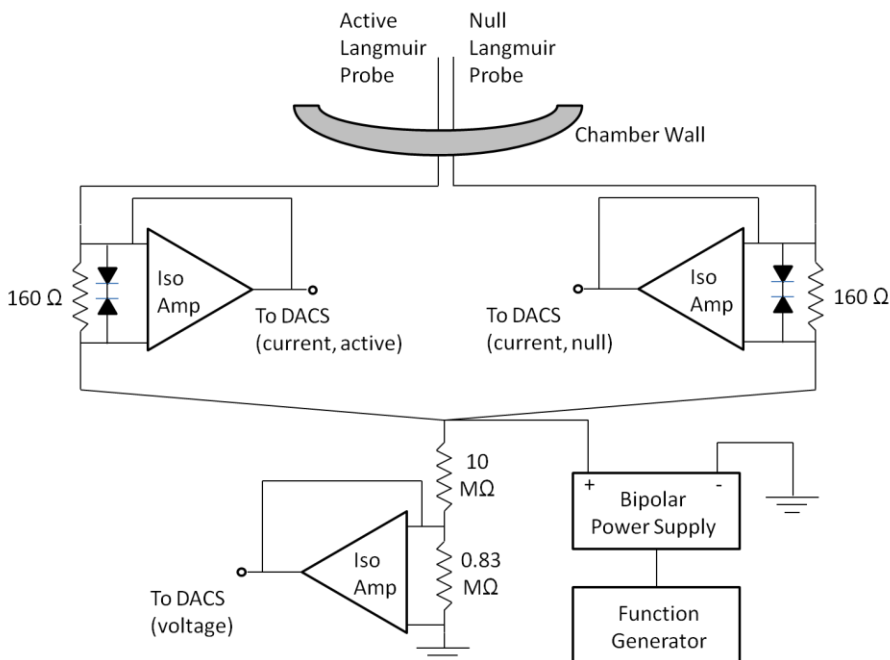
- Electrostatic probe rake comprised of a near-field Faraday probe, Langmuir probe, and two emissive probes (one for redundancy)
- Probes swept in radial direction at approximately 250 mm/s to minimize residence time in front of thruster for increased probe life
- Interrogation zone was approximately $\pm 3 D_{T,m}$ in the radial direction about thruster centerline, and $0.1 - 2 D_{T,m}$ downstream of exit plane in axial direction, with resolution chosen to be fine near the thruster where large gradients were expected



Electrostatic Probe Setup – Langmuir Probe

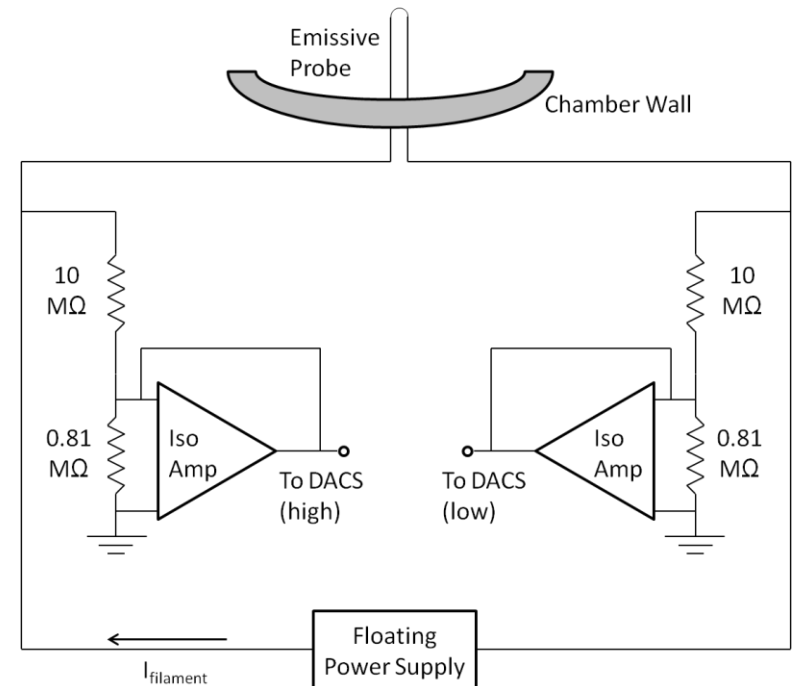
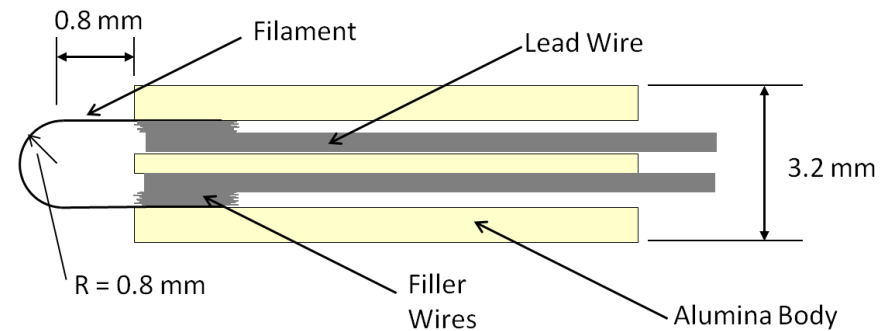


- Langmuir probe made of pure tungsten wire 0.250 mm in diameter and 2 mm long
- Encapsulated “null” probe isolated from plasma to characterize line capacitance currents to be subtracted out in post-processing
- Currents measured across 160- Ω carbon resistors, with voltage being measured across a voltage divider
- All signals passed through voltage-following isolation amplifiers to protect the data acquisition system
- Probes swept from -95 to +15 V using a 125 Hz triangle wave, with 50 kHz sampling rate producing 200-pt I-V characteristics every mm in radial direction
- Data analysis largely follow simple Langmuir probe theory

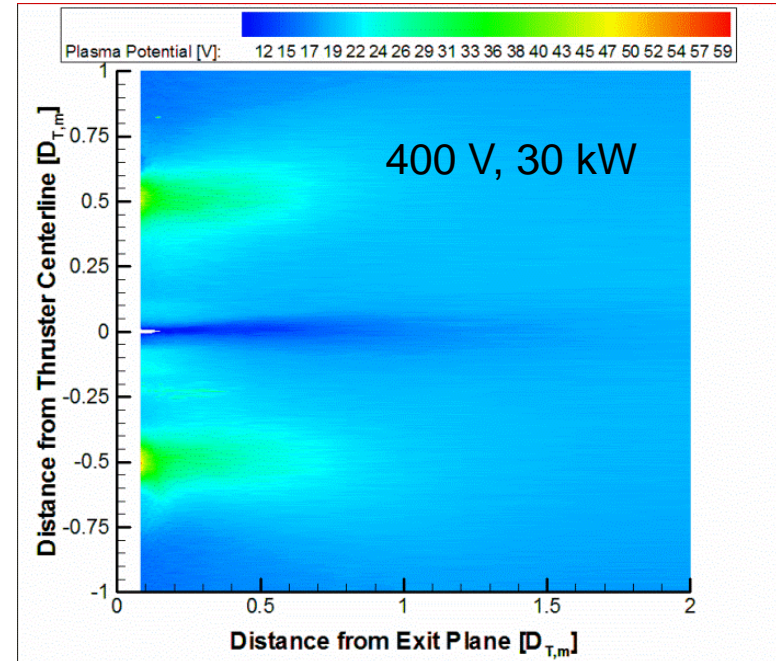
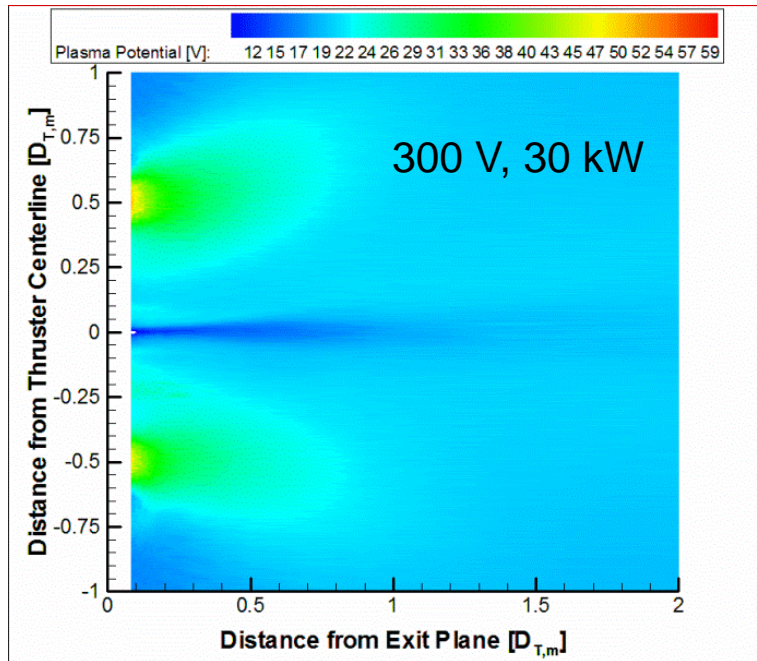
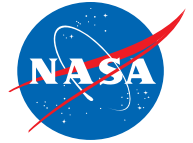


Electrostatic Probe Setup – Emissive Probe

- Emissive probe filament comprised of 0.102-mm-diameter 1% thoriated tungsten wire bent into a loop with a radius of curvature of 0.8 mm
- Pure tungsten wires used for lead wires as well as “filler” wires for tight fit between filament and lead wires
- Floating power supply provided necessary current to heat filament to thermionic emission
- Potential measured on each side of filament using voltage dividers, and averaged in post-processing
- Each radial sweep downsampled to 2000 points to provide approximately 1 mm resolution in the radial direction



Test Results – Plasma Potential Contours

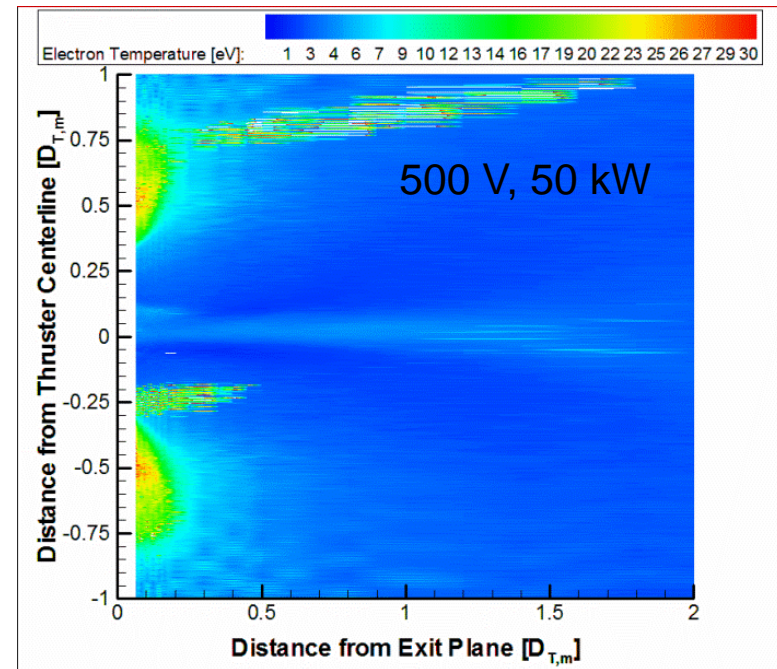
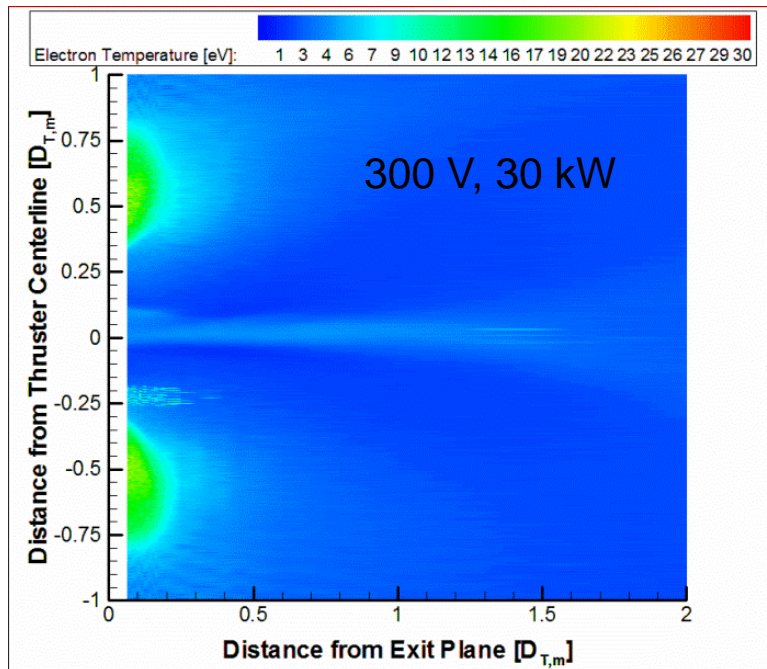


- Limited data set due to fragility of emissive probes – two operating conditions presented here
- Most of near-field plume is 20-25 V above cathode potential, with acceleration zone being limited to $\sim 0.4 D_{T,m}$ from thruster exit plane
- Maximum measured potentials are 50 – 55 V above cathode potential
- Dropoff in radial direction looks sharper at 400 V, indicating a more collimated beam

Test Results – Electron Temperature Contours



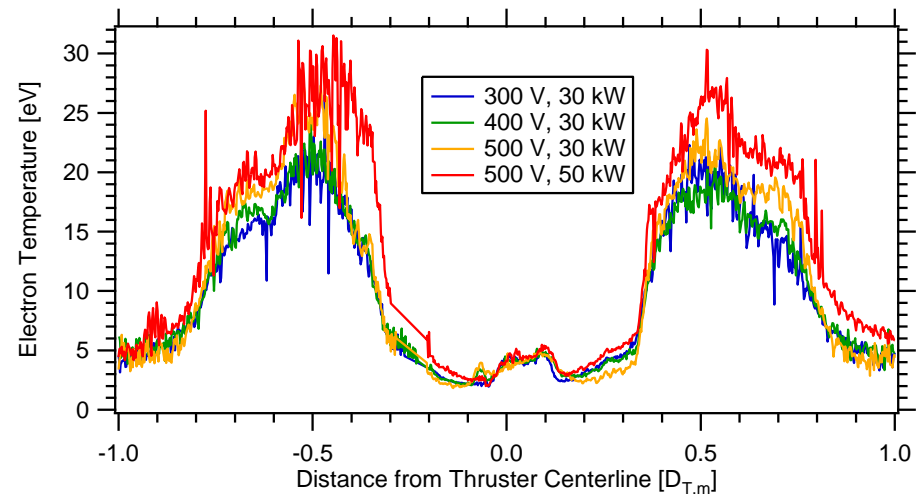
- Similar isothermal line structure seen across all four operating conditions presented in paper (300,400,500 V at 30 kW, 500 V at 50 kW)
- Most of near-field plume at constant temperature $\sim 2\text{-}5\text{ eV}$, with high-temperature region being limited to $0.25 D_{T,m}$ from thruster exit plane
- Maximum measured temperatures varied between $24 - 32\text{ eV}$ depending on operating condition



Isothermal Line Structure – Comparison Across Operating Conditions



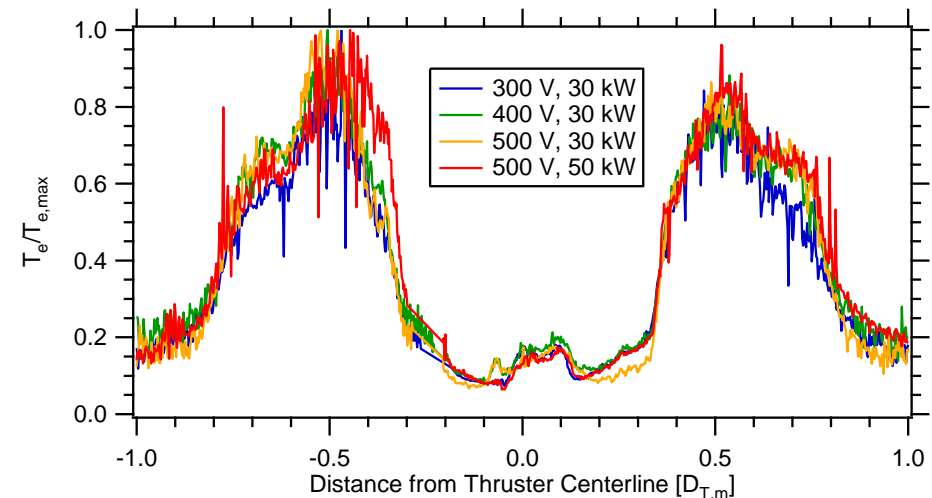
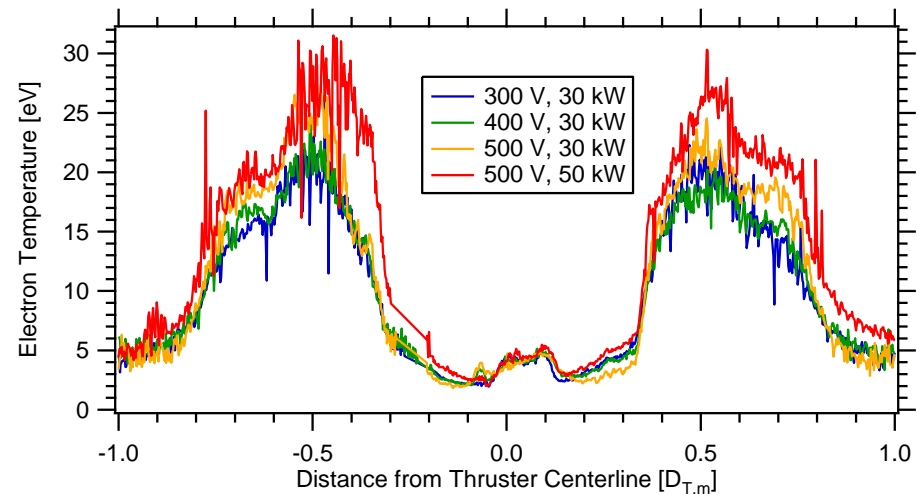
- Radial profiles of electron temperature at $0.06 D_{T,m}$ from thruster exit plane show similar structure across operating conditions
- Peak temperature seen to maximize around the channel centerline, with a rapid dropoff as thruster centerline is approached and a more gradual dropoff away from thruster centerline



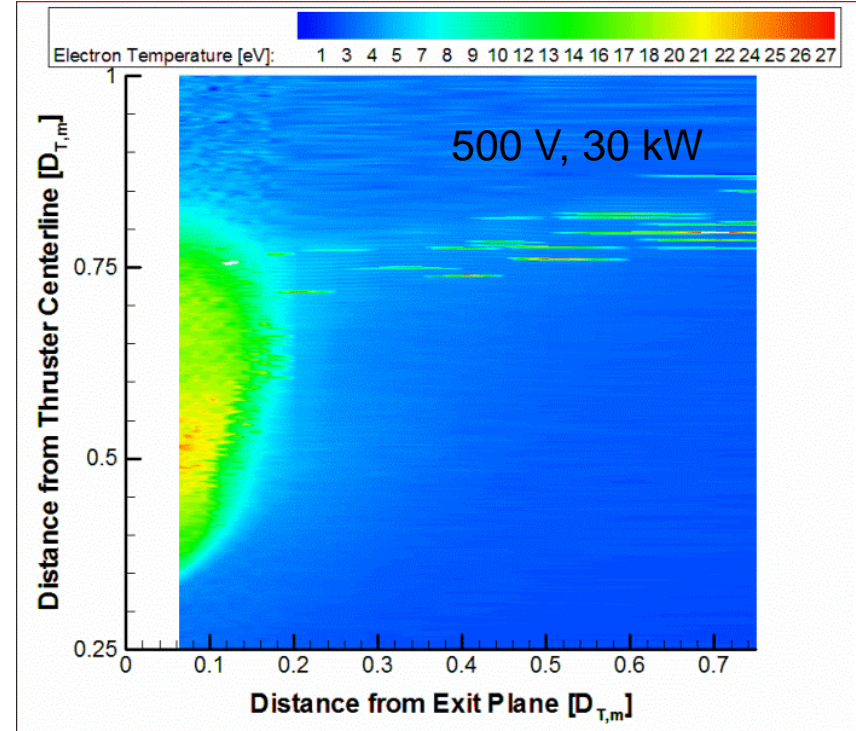
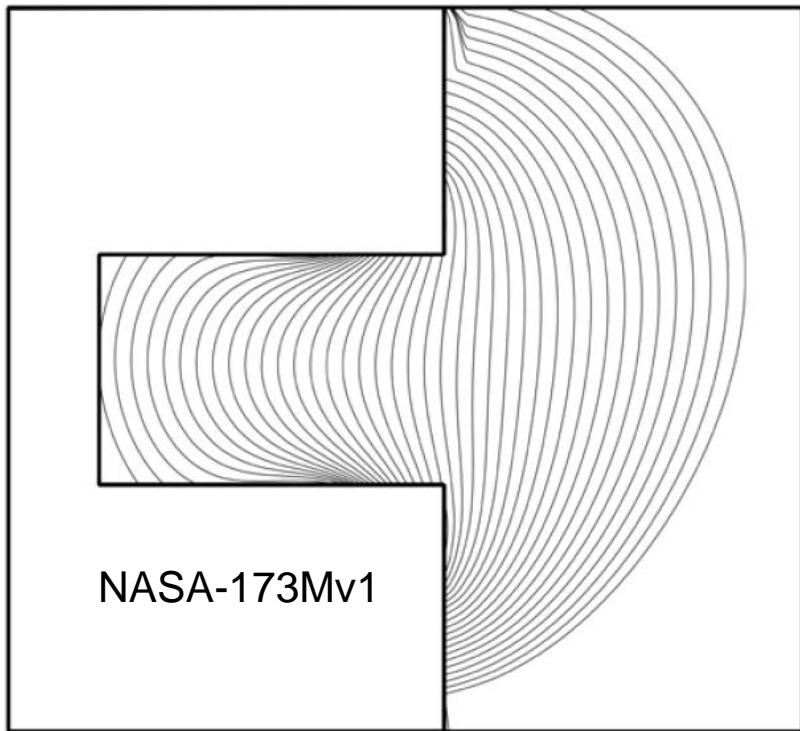
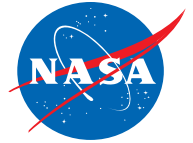
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- Non-dimensionalizing each profile by the maximum temperature shows them collapsing on top of each other, indicating a near universal shape across operating conditions



Isothermal Line Structure – Comparison to Magnetic Field Topology

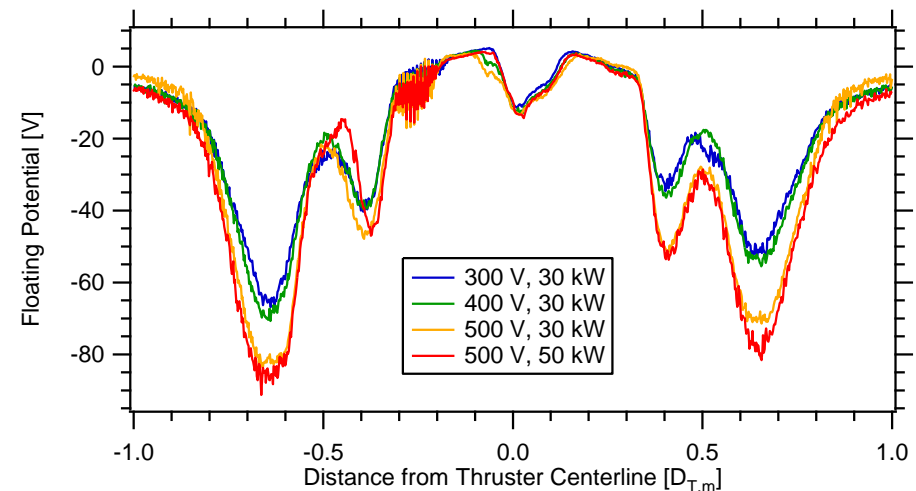
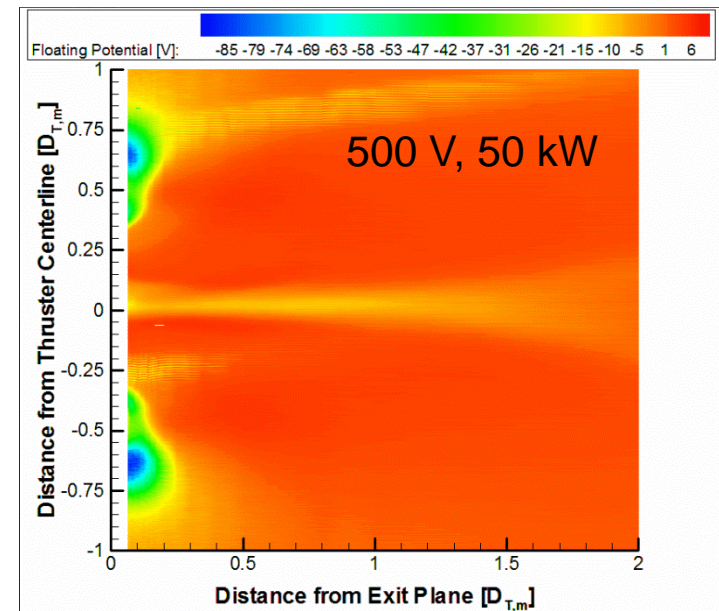


- Comparing the isothermal lines to a typical magnetic field topology in the near-field shows similarity in the structure, indicating that the magnetic field is likely shaping the isothermal lines in this region
- The universal shape across operating conditions is consistent with the fixed shape of the magnetic field during the study

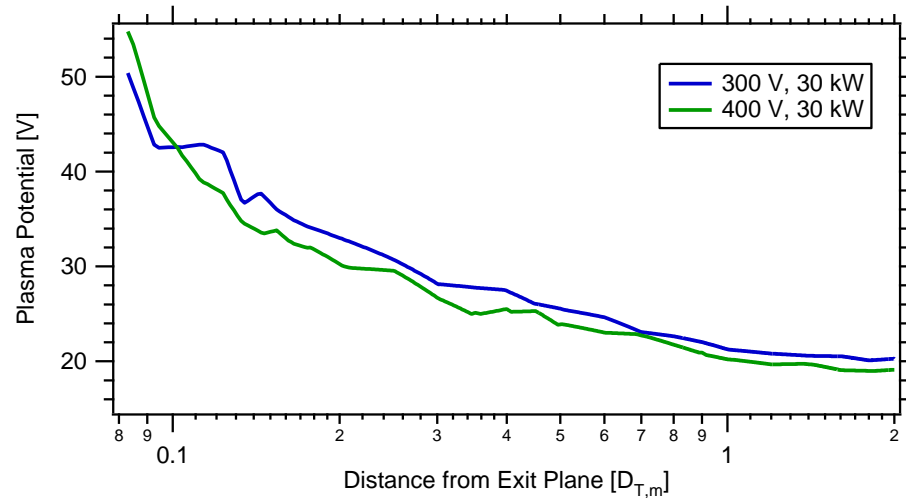
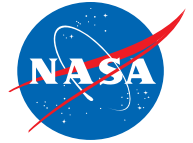
Isothermal Line Structure – Effects on Plasma Near Magnetic Pole Surfaces



- Low floating potentials approaching 90 V below facility ground observed in regions adjacent to channel bounds
- Isothermal line structure brings high temperatures from downstream of the channel to regions of relatively low plasma potential and density
- Effect is more pronounced at higher voltages where electron temperatures are higher in the plume
- This would create thick, perhaps strong sheaths at the magnetic pole surfaces
- Will need to account for this effect to properly capture ion saturation measurements in these regions



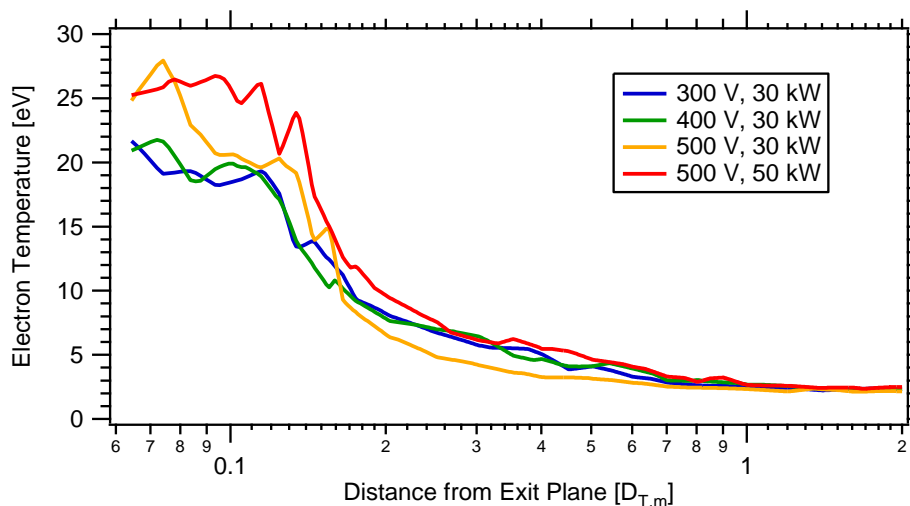
Acceleration Zone/High-temperature Region in the Near Field Plume



- Axial profiles of plasma potential and electron temperature show rapid increase as thruster exit plane is approached

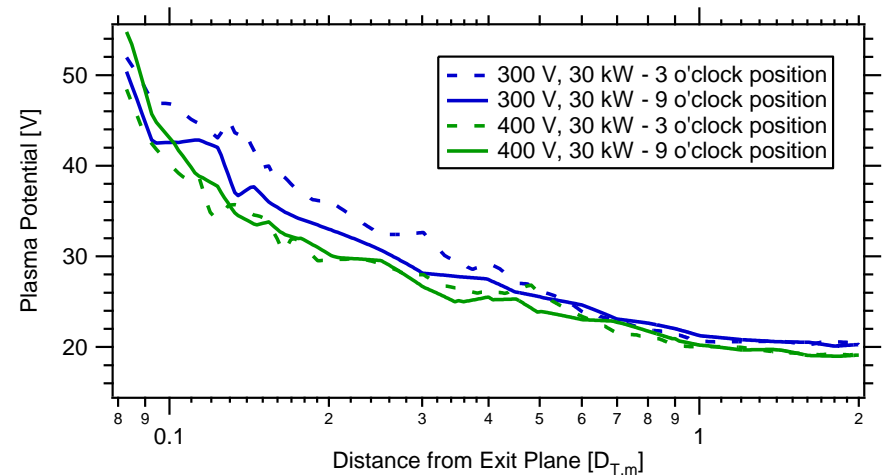
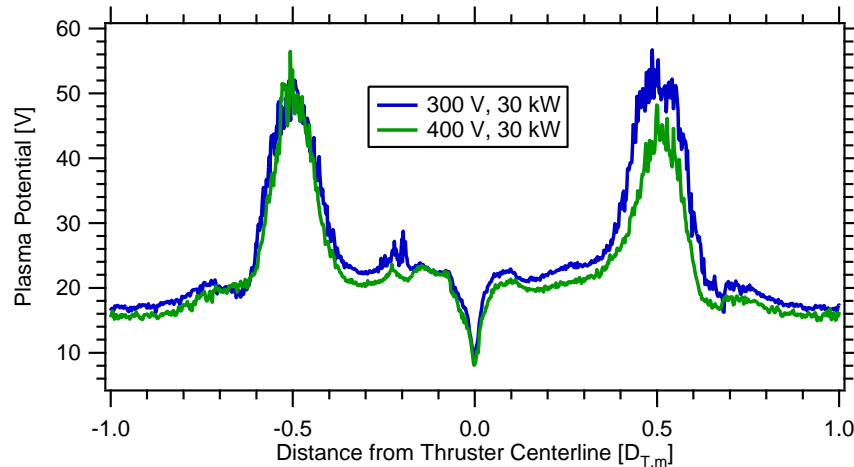
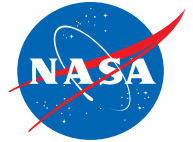
- Approximately 10% of the potential rise towards anode is captured in the near-field plume

- Average electron heating is 0.52 eV/V at 300 V and 0.46 eV/V of potential at 400 V, which is much higher than previously reported values on other thrusters (0.07 – 0.16 eV/V)



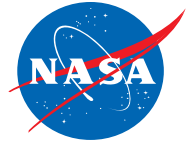
- More data within the acceleration zone is required to determine this “enhanced” electron heating in the near-field plume

Comparison of Clocked Positions for Azimuthal Symmetry



- Due to interrogation method, both 3 o'clock and 9 o'clock positions can be compared to verify azimuthal symmetry
- Comparison of radial profiles of plasma potential show slight asymmetries
- Acceleration zone locations differ by $\sim 0.01 D_{T,m}$, indicating acceleration zone symmetry within $\pm 0.005 D_{T,m}$
- Cannot be due to systematic error such as table misalignment because of varying direction of differences

Conclusions



- An electrostatic probe array was used to interrogate the near-field plume of the 50-kW NASA-457Mv2
- Data shows that the acceleration zone is limited to $0.4 D_{T,m}$ from the exit plane and the high-temperature region is limited to $0.25 D_{T,m}$ from the exit plane
- Isothermal lines were found to exhibit a near-universal structure across operating conditions that appears to be shaped by the magnetic field topology
- The isothermal line structure brings high-temperature electrons to a region near the magnetic poles that is characterized by low potential and density, resulting in very low floating potentials
- Analysis of the acceleration zone indicates possible enhanced electron heating in the near-field plume
- Comparison of the two interrogated clocked positions indicates symmetry of the acceleration zones within $\pm 0.005 D_{T,m}$
- These data are deemed valuable to ongoing modeling efforts and the development of a high-power, high-performance long life Hall thruster



Questions?