Optimizing Adamantane Plasma Thruster Efficiency via 2-D Simulations

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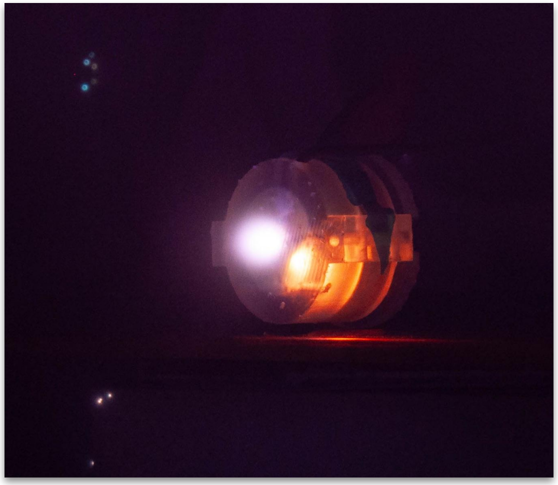
Motivations

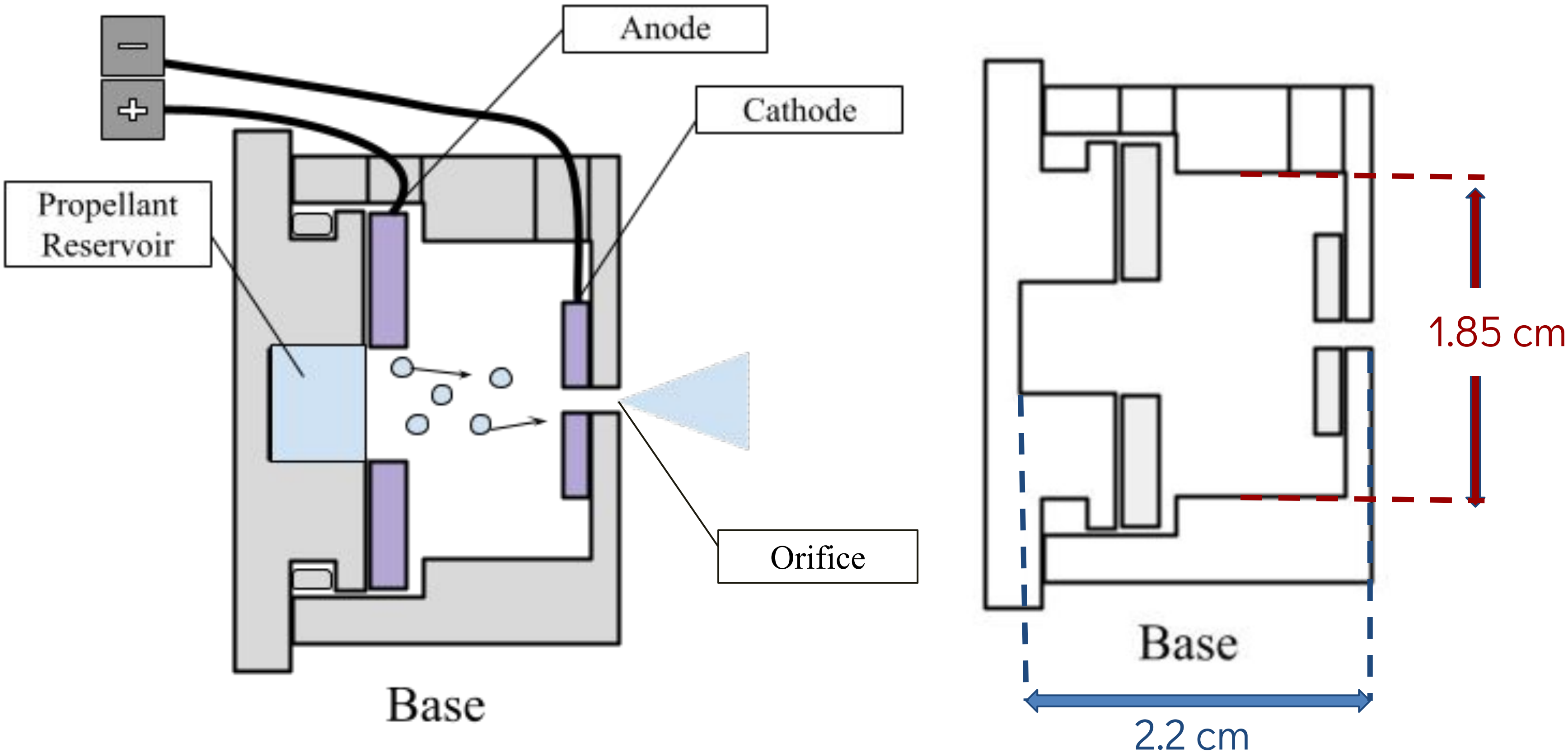
- Need to solve common issues in electric propulsion
- Developing Adamantane-based electric propulsion thruster at USC ASPEN Lab
- Need to characterize the thruster

ASPEN

Advanced Spacecraft Propulsion & Energy Lab

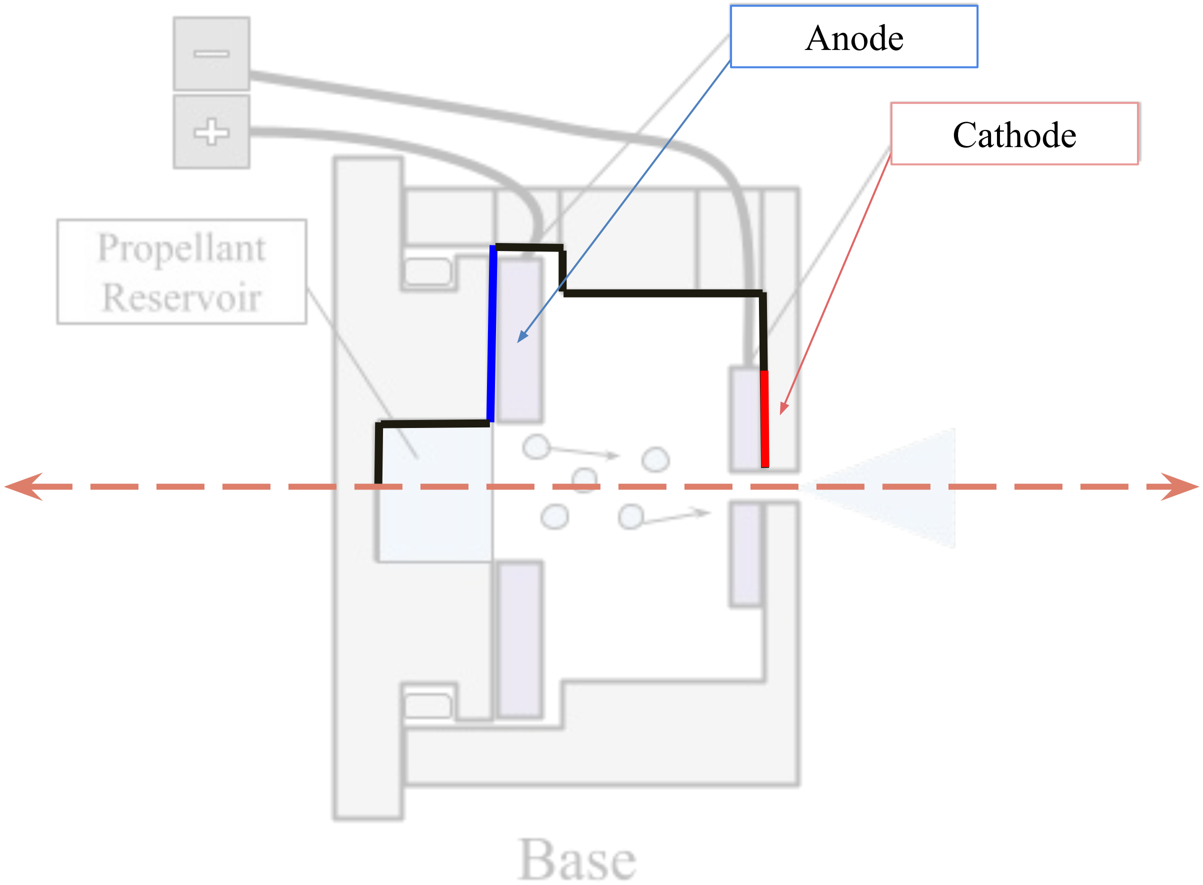


Base Geometry



Base Geometry

- Derive plasma characteristics
- Compare thrust, specific impulse, plasma density, mass flux, exit velocity



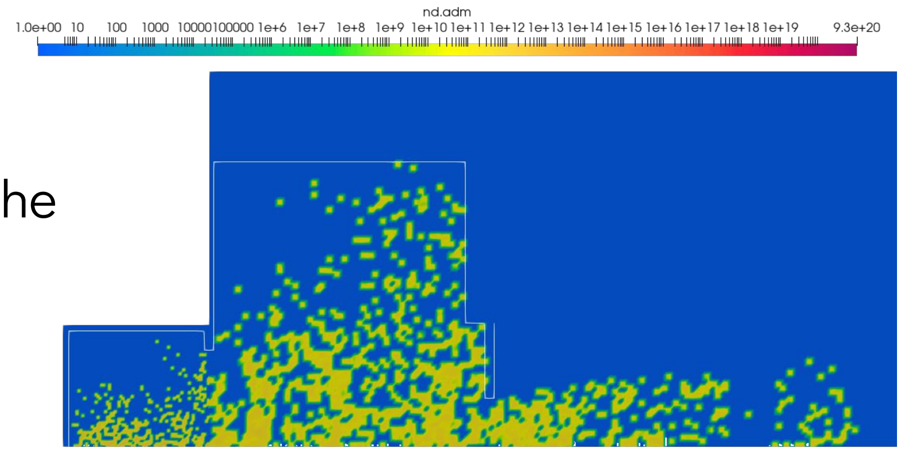
Starfish

- Two-dimensional, open-source plasma & rarefied gas simulation code
- Models low-density plasmas using:
  - Electrostatic Particle-in-Cell (ES-PIC)
  - Monte Carlo Collisions (MCC)

- Operates on structured Cartesian or body-fitted stretched meshes
- Used for simulating thruster plumes and other plasma dynamics

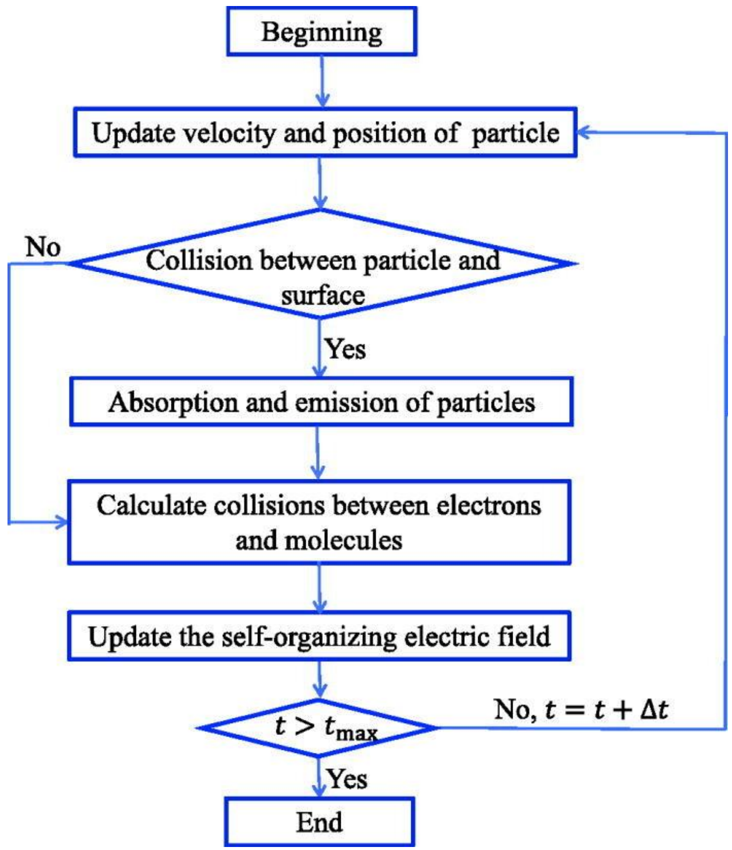
How Plasma is Modeled

- **Electrostatic Particle-In-Cell:**
  - Particles grouped into "macroparticles," representing velocity distribution samples
  - Simulates charged particles using the Lorentz force instead of direct Coulomb interactions
  - Assumes low-density plasma → negligible self-induced magnetic fields



How Plasma is Modeled

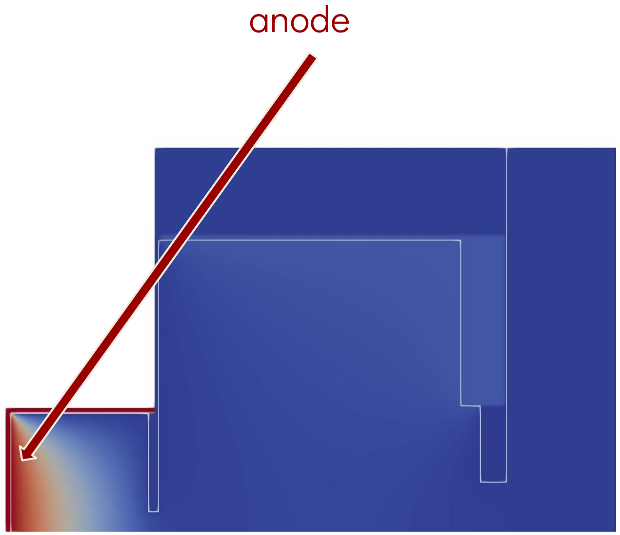
- **Monte Carlo Collisions:**
  - Models plasma-neutral collisions probabilistically
  - Includes charge exchange, ionization, and elastic scattering
  - Determines how ions interact with neutrals and walls



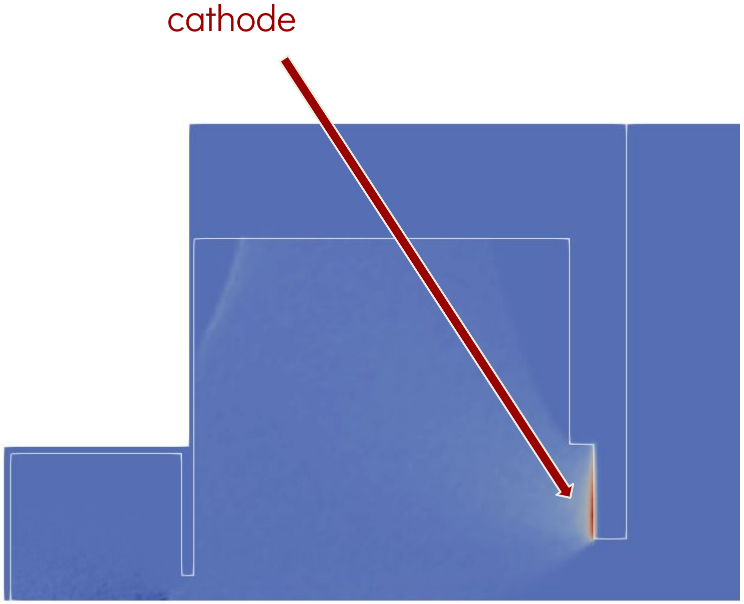
Flowchart of particle-in-cell Monte Carlo collision simulation [6].

Input Variables

- Boundaries and Inputs
    - Specified by material
    - Material type: insulator, anode, cathode
    - Charge value



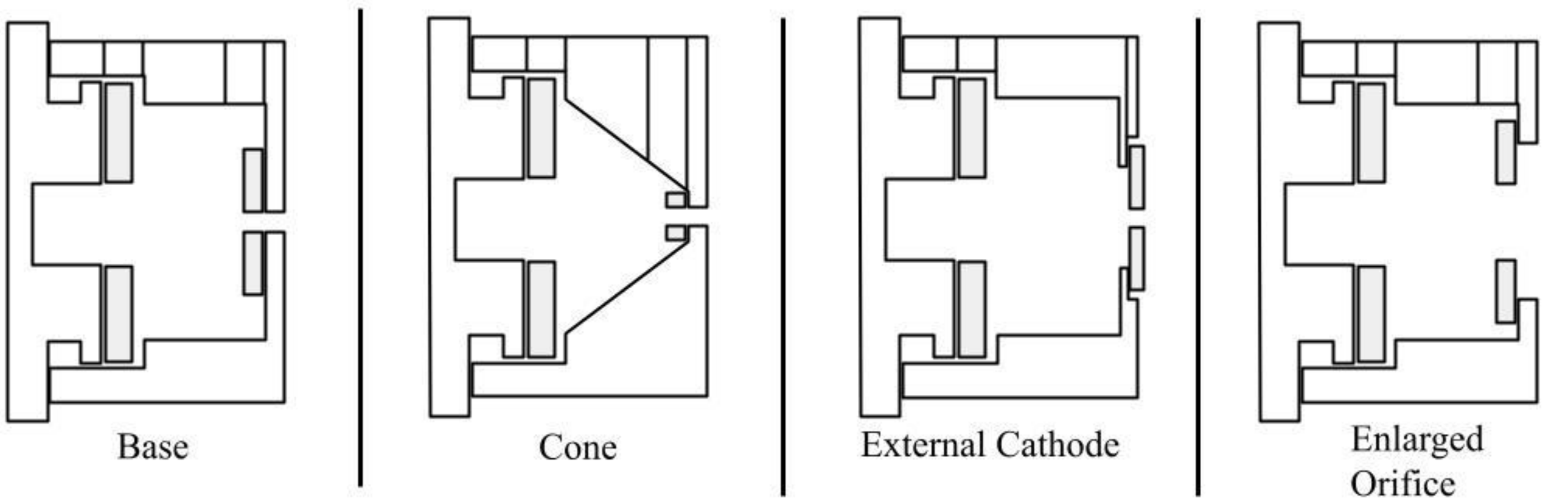
- Plasma Potential (base thruster)



- Electron Density (base thruster)
    - Moves in the direction of the propellant chamber

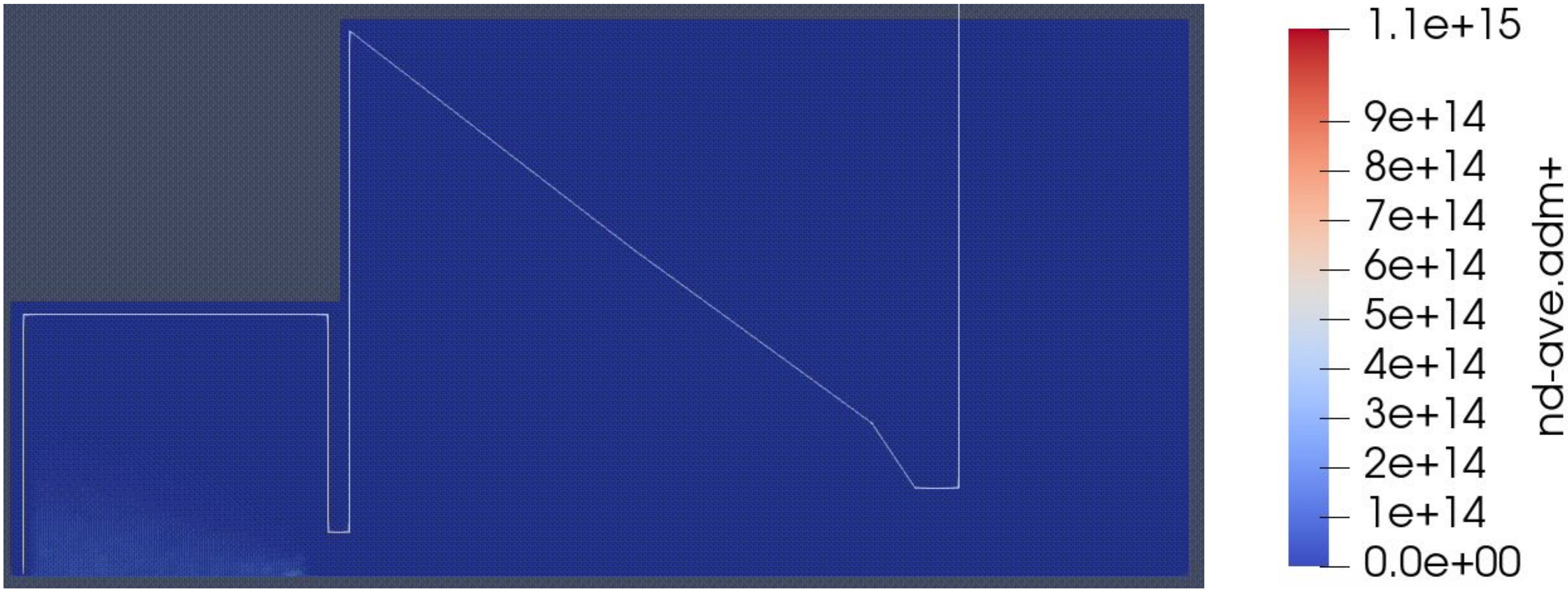
Geometries

- **Base:** Reference geometry to set baseline expectations
- **Cone:** Sloped walls to naturally direct plasma to orifice
- **External Cathode:** Combat carbon buildup in ionization chamber
- **Enlarged orifice:** Larger exit area → more thrust



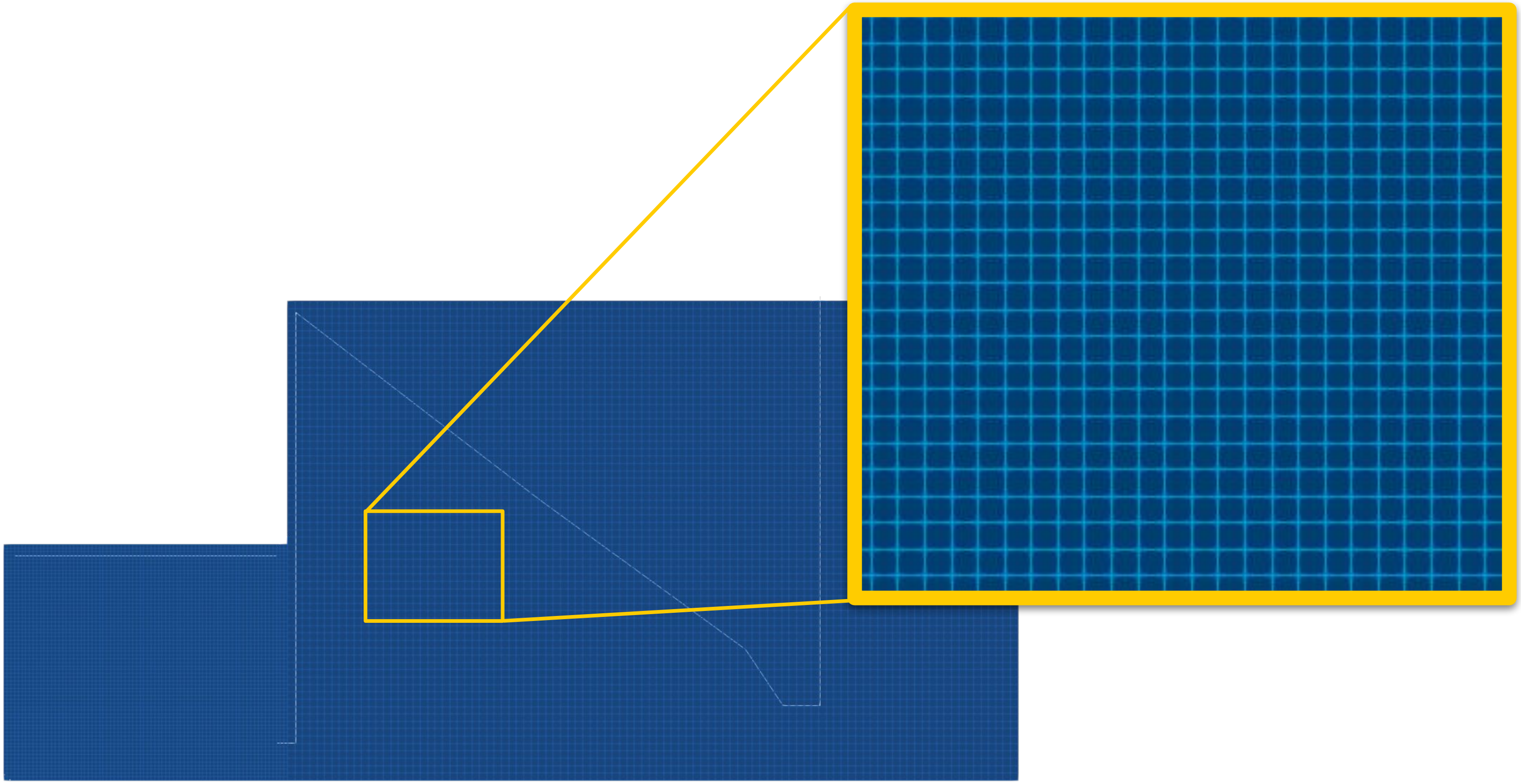
Four iterations of the thruster used for simulations.

Results



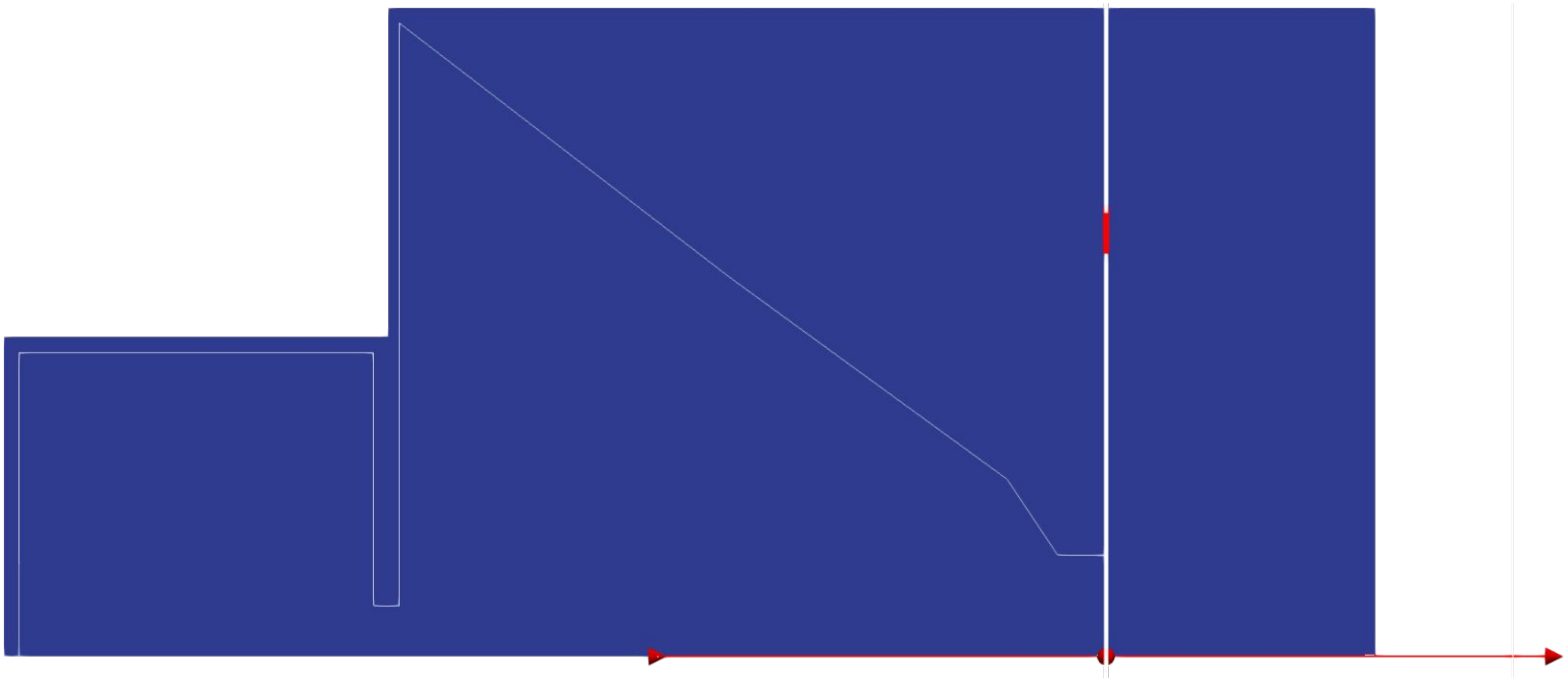
Mass Flux over cone geometry over 600 nanoseconds

Data Processing



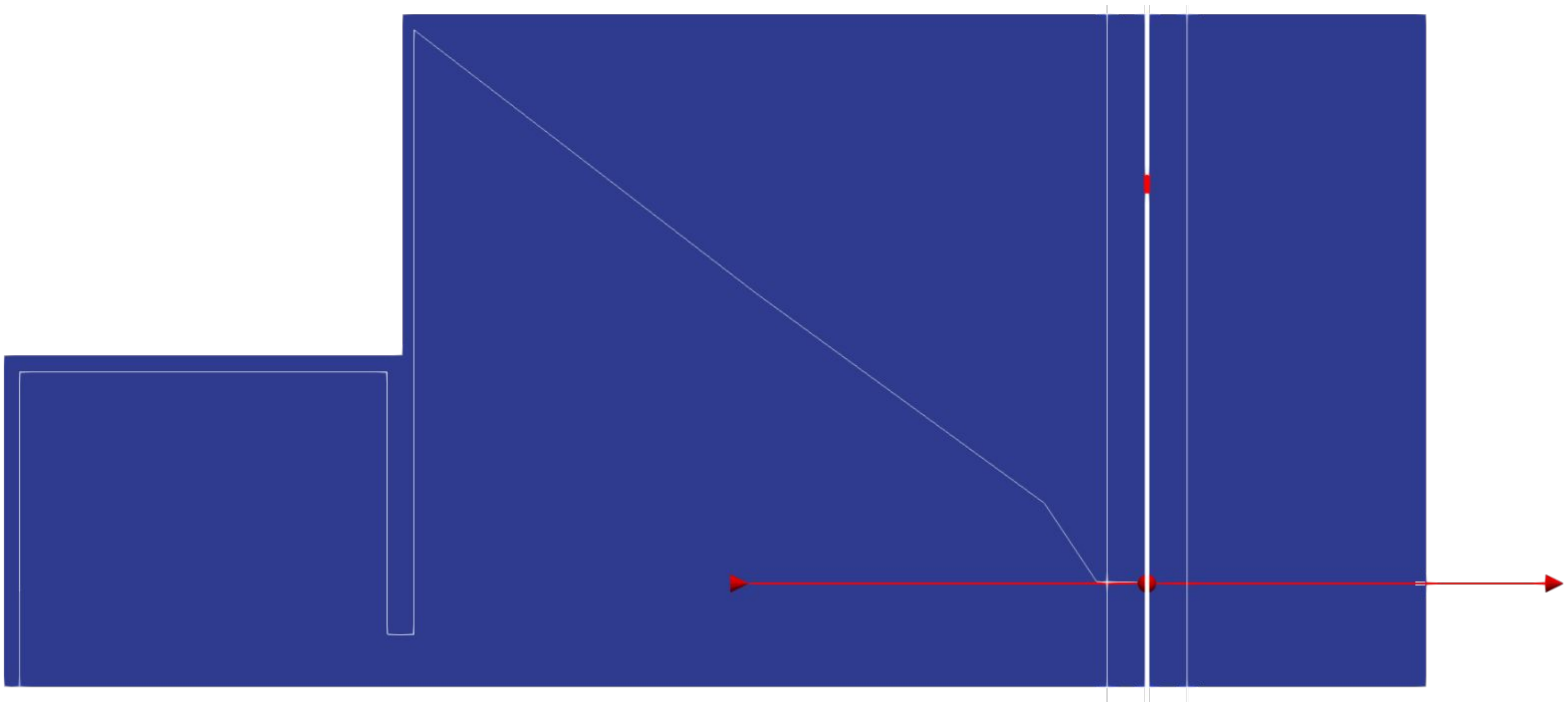
Mesh Area

Data Processing



Inserting Slice

Data Processing



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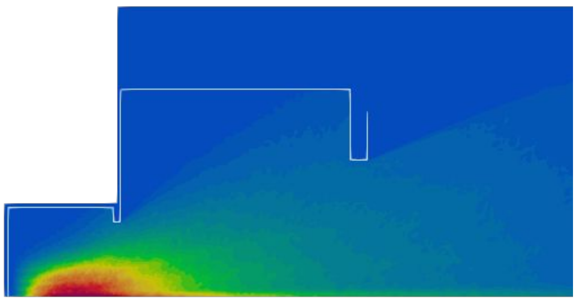
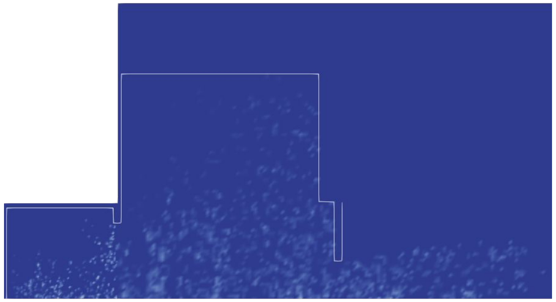
Data Processing

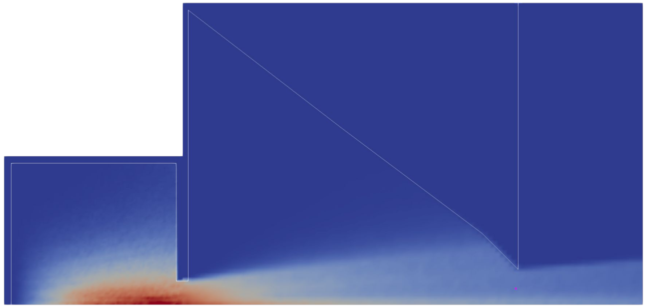


Enlarged Orifice

Base Model



External Cathode



Cone

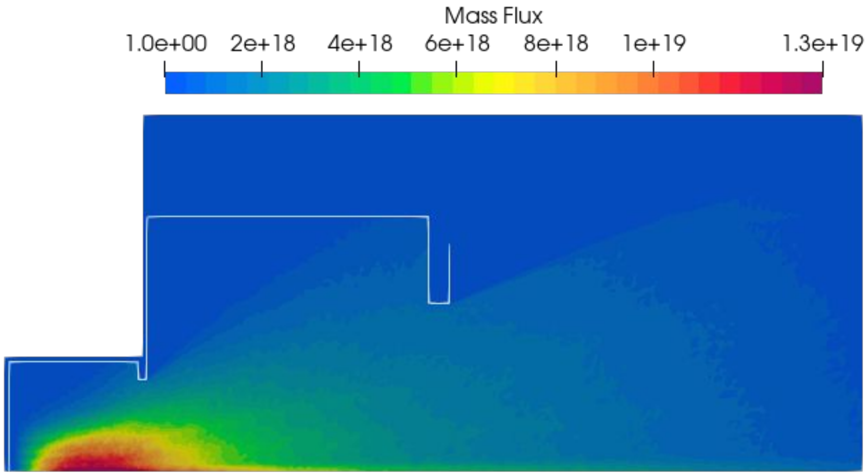
Mass Flux over each geometry at 600 nanoseconds

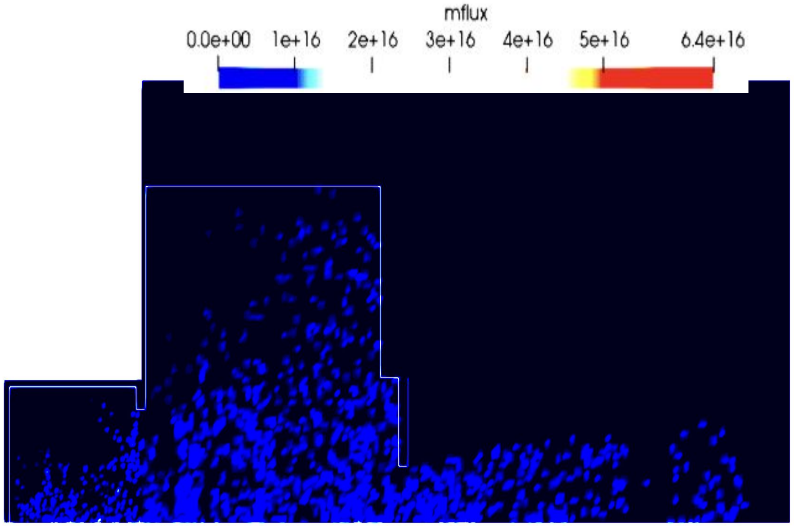
Results

Properties for plasma and propellant flow from simulation of different geometries.

Internal Geometry	Specific Impulse (I_{sp}, s)	Mass Flux (j_{mm}, kg / m^2 s)	Exit Velocity (V_e, m / s)	Thrust (F, N)
Base Thruster	1,100	2.4×10^{-10}	36,000	1.3×10^{-11}
Large Orifice	4,000	2.1×10^{-9}	40,000	5.6×10^{-9}
External Cathode	5,000	3.1×10^{-13}	49,000	4.6×10^{-13}
Cone	3,600	1×10^{-9}	36,000	4.1×10^{-10}

Results





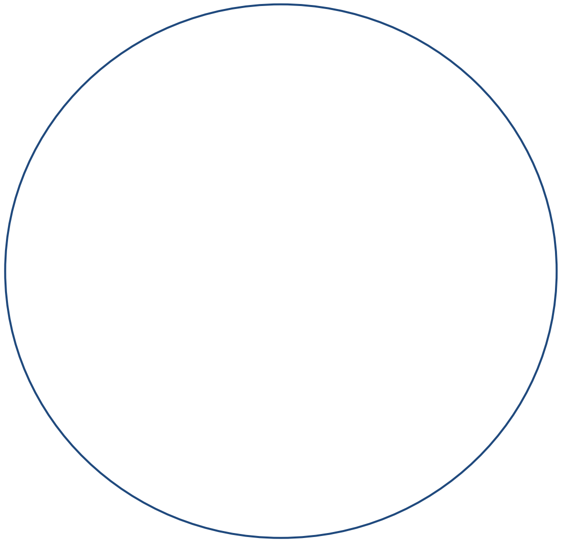
Enlarged Orifice
- Largest Thrust

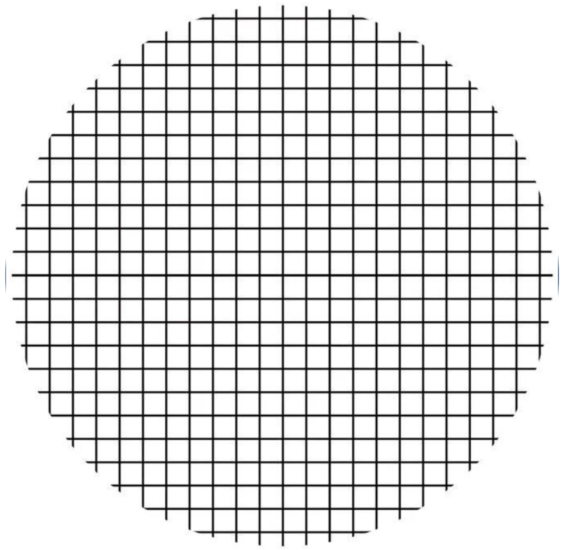
External Cathode
- Largest Specific Impulse

Mass Flux at 600 nanoseconds

Future Work

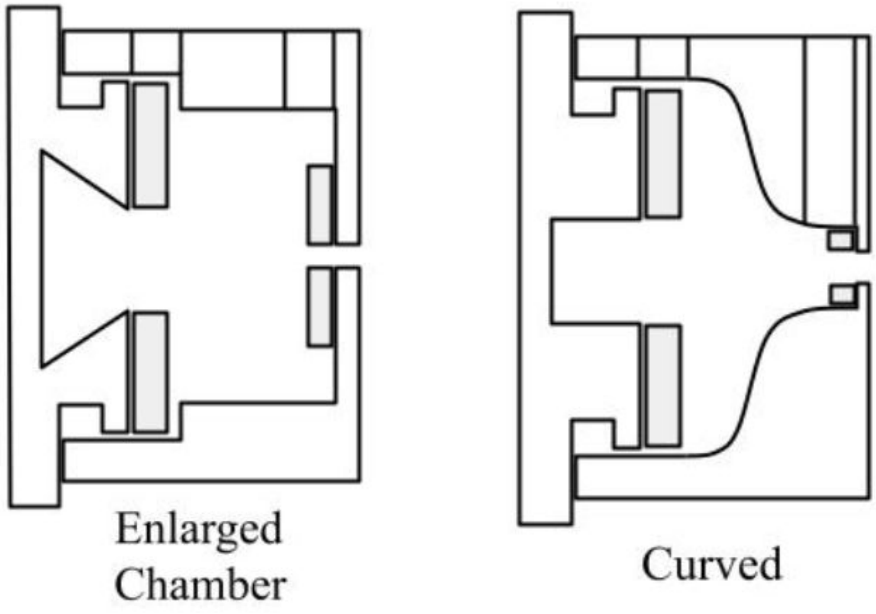
- Adamantane fragmentation and ionization
  - Reaction Rates
- Sublimation Rate
- Integrating Starfish area to physical thruster

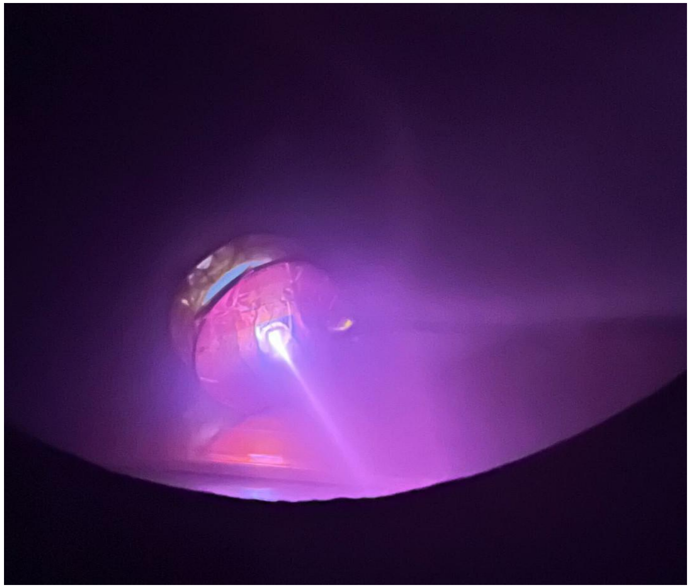




Future Work

- Continue simulating new geometries
- Reference with test team





Q & A

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Bonus slides

$$j_{mp} = \frac{particles}{seconds\ (area)} = \text{“nd.adm+”} * \text{“u.adm+\_v.adm+\_X”} \quad (1)$$

$$j_{mm} = j_{mp}\frac{M}{N_A} \quad (2)$$

$$\dot{m} = j_{mm}A_T = j_{mm}(\pi r^2) \quad (3)$$

$$F = \dot{m}V_e \quad (4)$$

$$I_{sp} = \frac{F}{\dot{m}\, g} \quad (5)$$

Bonus Slides

- Typical thrust of an ion thruster : about 240 mN
- Typical specific impulse of an ion thruster: 4200 s

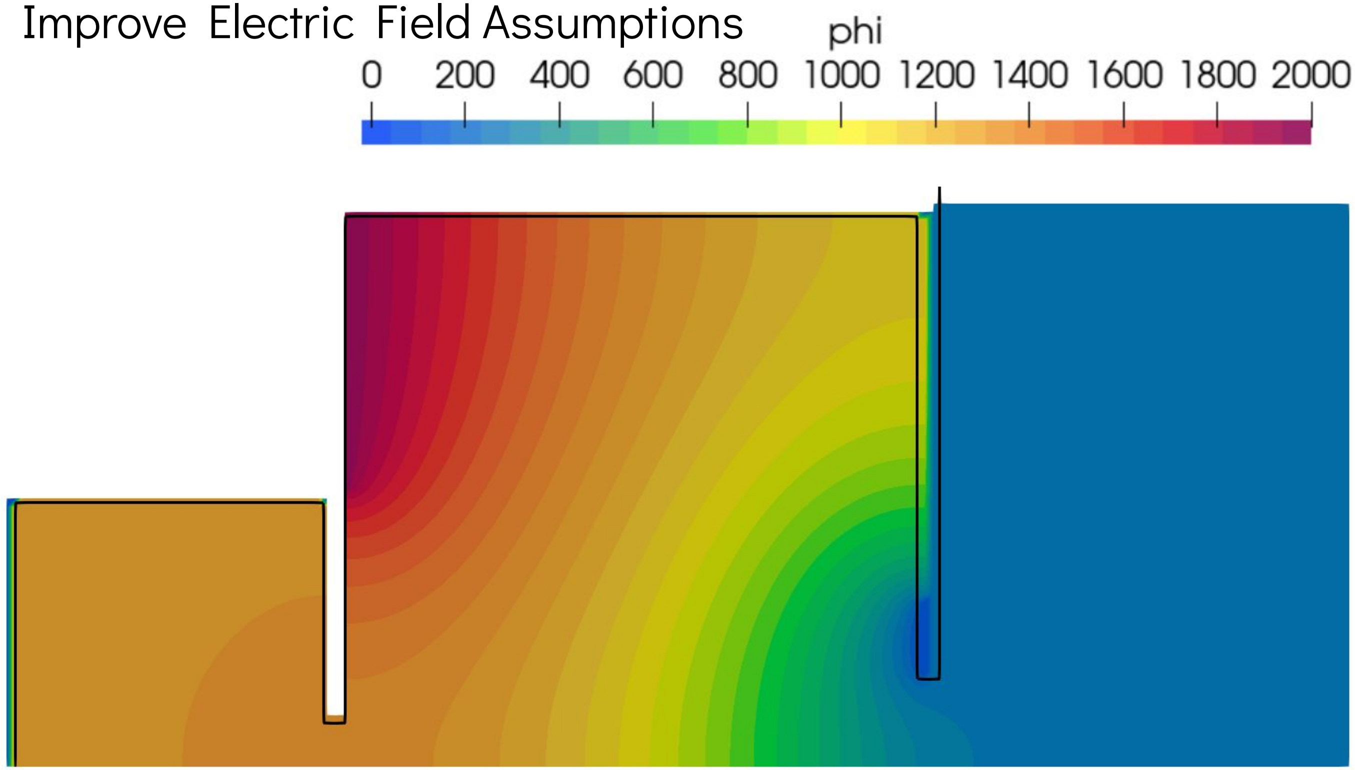
Bonus Slides

Additional properties for plasma and propellant flow from simulation of different geometries.

Internal Geometry	Plasma Density (n_{adm}, particles / m^3)	Particle Flux (j_{mp}, particles / m^2 s)	Mass Flow Rate ($\dot{m}$, kg / s)
Base Thruster	2.4×10^{13}	1.1×10^{15}	3.7×10^{-16}
Large Orifice	5.1×10^{13}	9.3×10^{15}	1.4×10^{-13}
External Cathode	1.5×10^{11}	1.4×10^{12}	9.4×10^{-18}
Cone	1.2×10^{11}	4.4×10^{15}	5.8×10^{-18}

Bonus Slides

- Improve Electric Field Assumptions



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