

# Operating Principles of Hall Effect Thrusters

Your Name

Electric Propulsion Overview

December 1, 2025

# What is a Hall Effect Thruster?

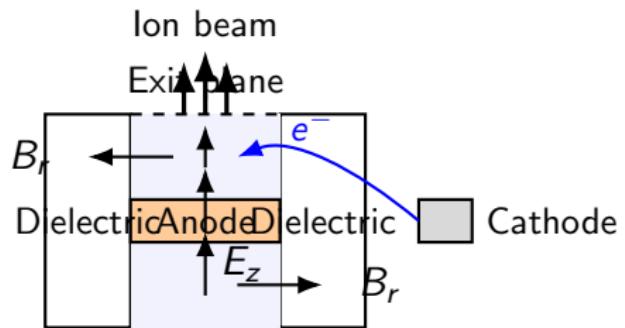
- A Hall Effect Thruster (HET) accelerates ions electrostatically using a crossed electric and magnetic field geometry.
- Key feature: **electrons are magnetized, ions are not.**
- Electrons undergo an azimuthal  $\mathbf{E} \times \mathbf{B}$  Hall drift.
- Unmagnetized ions are accelerated axially by the electric field and exit at  $\sim 10\text{--}20$  km/s.
- Quasi-neutral plasma throughout; no grids.

# Hall Thruster Geometry (Annular Channel)

- Ceramic discharge channel with:
  - Radial magnetic field  $B_r$
  - Axial electric field  $E_z$
  - Neutral gas injection near anode
  - Cathode external to the channel
- Crossed-field configuration traps electrons, enabling efficient ionization and acceleration.

*(See next slide for TikZ schematic.)*

# TikZ Schematic: Hall Thruster Cross-Section



# Electron and Ion Magnetization

**Electrons:** strongly magnetized

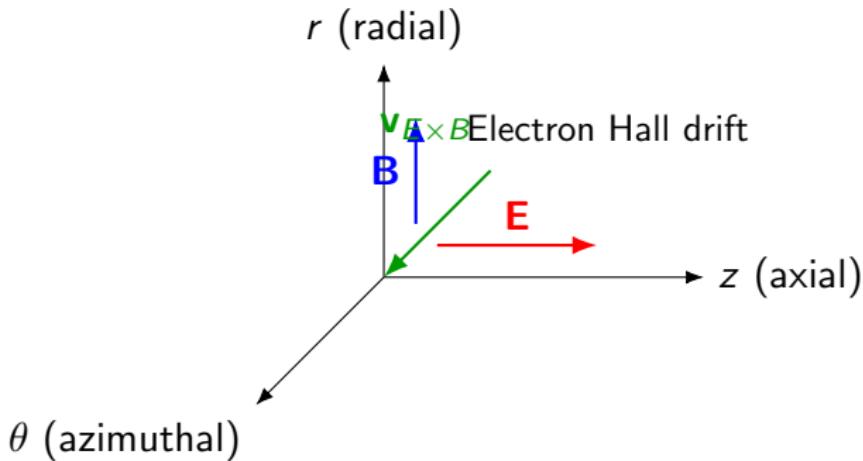
$$r_{L,e} = \frac{m_e v_\perp}{eB} \ll \text{channel size}$$

**Ions:** effectively unmagnetized

$$r_{L,i} = \frac{m_i v_\perp}{eB} \gg \text{channel size}$$

- Electrons are confined laterally by  $B_r$ , limiting axial motion.
- Ions move freely along the electric field.
- Magnetized electrons → high ionization efficiency.

# $\mathbf{E} \times \mathbf{B}$ Hall Drift (TikZ View)



- Crossed fields:

$$\mathbf{v}_{E \times B} = \frac{\mathbf{E} \times \mathbf{B}}{B^2}$$

- For HET:

$$\mathbf{E} = E_z \hat{z}, \quad \mathbf{B} = B_r \hat{r}$$

$$\Rightarrow \mathbf{v}_\theta = \frac{E_z}{B_r} \hat{\theta}$$

# $\mathbf{E} \times \mathbf{B}$ Hall Drift

- Electrons experience crossed electric and magnetic fields:

$$\mathbf{v}_{E \times B} = \frac{\mathbf{E} \times \mathbf{B}}{B^2}$$

- For HET geometry:

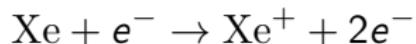
$$\mathbf{E} = E_z \hat{z}, \quad \mathbf{B} = B_r \hat{r}$$

$$\Rightarrow \mathbf{v}_\theta = \frac{E_z}{B_r} \hat{\theta}$$

- This azimuthal electron drift current is the **Hall current**.
- Drift enhances electron residence time, boosting ionization.

# Ionization and Acceleration

- Neutral xenon injected at the anode.
- Magnetized electrons drift azimuthally, colliding with neutrals:



- Ionization zone forms near the channel exit.
- Ions accelerate axially:

$$F = qE_z, \quad v_i = \sqrt{\frac{2qV_b}{m_i}}$$

- Typical ion energies: 200–300 eV.

# Quasi-Neutral Plasma Acceleration

- Unlike gridded ion engines (GITs), HETs maintain **quasi-neutral plasma** throughout the acceleration region.
- No space-charge-limited extraction: electron confinement by  $B_r$  limits axial mobility.
- Very high ion current densities are achievable ( $\sim$  tens of mA/cm $^2$ ).
- The thruster and cathode together produce a **neutralized ion beam**.

# Cathode Functions

- Located outside the channel.
- Provides electrons for:
  - Beam neutralization
  - Sustaining the discharge current
  - Replacing electrons lost to the anode
- Cathode coupling is essential for efficiency and stability.

# Hall Thrusters vs. Gridded Ion Thrusters (GIT)

	<b>Hall Effect Thruster</b>	<b>Gridded Ion Thruster</b>
Ion acceleration	Electrostatic, in quasi-neutral plasma; $E_z$ in channel	Electrostatic, through grid apertures; strong sheath and space-charge region
Ion optics	No grids; plasma expansion at exit	Multi-grid optics (screen, accel, often decel); tightly controlled beam
Electron dynamics	Strongly magnetized; $\mathbf{E} \times \mathbf{B}$ Hall drift	Not strongly magnetized (typically); electrons confined by grids
Limiting physics	Cross-field electron transport	Child–Langmuir space-charge limit in grid gaps
Thrust-to-power	$\sim 60\text{--}70 \text{ mN/kW}$	Typically lower, $\sim 30\text{--}50 \text{ mN/kW}$
Efficiency	$\sim 50\text{--}65\%$	$\sim 60\text{--}70\%$ (varies with design)
Lifetime limiters	Channel wall erosion,	Grid erosion,

# Advantages of Hall Thrusters

- High thrust-to-power ratio (60–70 mN/kW).
- Efficient: 50–65%.
- Long lifetime with magnetic shielding designs.
- Simple, robust design: no grids, tolerant to contamination.
- Widely used for Earth-orbit raising, station-keeping, and deep-space missions.

# Summary of HET Operation

- Crossed  $E_z$  and  $B_r$  fields trap electrons and cause a strong  $\mathbf{E} \times \mathbf{B}$  Hall drift.
- Trapped electrons enhance ionization efficiency near the channel exit.
- Ions, unmagnetized, are accelerated by the axial electric field.
- A cathode provides electrons to neutralize the ion beam.
- Result: efficient, stable, quasi-neutral plasma acceleration.