# Power Density and Temperature Effects on Hall-Effect Thruster Efficiency

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Abstract: A theoretical basis for power density and temperature effects on Hall effect thruster (HET) ionization efficiency and propulsive efficiency has been developed. Thruster efficiencies, including ionization, anode efficiency, mass utilization, voltage utilization, and current utilization, are quantitatively examined to determine the dominant loss mechanisms and underlying physics of HET operation with respect to the high thrust-to-power operating mode. Power density is varied from 5 to 120 W/cm<sup>2</sup> while the electron temperatures range from 5 to 50 eV. The understanding of the physics underlying the high thrust-to-power operating mode allows focused improvement on HET performance and efficiency.

## Introduction

Hall effect thrusters (HETs) have remained one of the largest areas of interest for research in electric propulsion over the past decades because HET performance is well suited to near and midterm needs of Department of Defense, commercial, and scientific missions. A typical HET design strives for either more efficient operation at high specific impulse<sup>1</sup> or high thrust-to-power (T/P) ratio. Previous theoretical analysis and experimental investigations have determined HET operating conditions at which each of these operating modes is achieved<sup>2,3</sup>. What remains to be understood, however, is a detailed understanding of the physics of each of these operating modes.

It is believed that power density has a large effect on HET performance considering the relevant effects in various HET operating modes. This theoretical analysis intends to quantify the dominant effects and losses through collision cross sections, collision frequencies, and thruster efficiencies to elucidate the important characteristics in high T/P operation. It also allows researchers to apply new ideas and concepts to improve HET performance.

Previous research has been conducted on low-voltage HET operating regimes in which loss mechanisms are identified and thruster efficiencies are calculated<sup>4,5</sup>. Shastry<sup>6</sup> has examined wall losses in HETs at various discharge voltages from 150 V to 600 V, and Mikilledes et al.<sup>7</sup> have identified loss mechanisms, along with a proposed solution, leading to channel erosion. These works have calculated efficiencies and loss mechanisms during respective operating conditions, but previous experimental studies have not correlated this data to power densities.

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# **Theoretical Basis**

The theoretical basis to determine HET loss mechanisms utilizes various plasma temperatures and power densities, representative of HET operating modes, to quantify efficiencies. Collision cross sections and collision frequencies are calculated based on kinetic theory. The degree of ionization and recombination is based on classical kinetic models. Wall losses are based on empirically derived relationships.

Electrons are assumed to be thermalized, such that the magnetic field lines are lines of equipotential. This assumption is based upon recent theoretical and experimental work on magnetic field shaping.<sup>8,9</sup>

## Analysis

Analysis of the theoretical basis developed in this paper will correlate relevant effects and loss mechanisms of high T/P HET operation to power density and plasma temperature. Furthermore, when it is known how and by how much each mechanism is affected by changes in HET plasma characteristics, researchers can focus on these areas to help develop more efficient HETs.

This work also strives to determine which particle collisions are dominant in various plasma conditions. This knowledge will help identify energy transfer and associate specific efficiencies with specific particle collisions and plasma conditions.

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