Power-to-Thrust Analysis: Modelling of Ionic Thruster Performance for Space Launch with MATLAB

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Innhold

I - Abstract and introduction

Abstract

This research essentially aims to investigate the power-to-thrust ratio of a smaller sized ionic thruster designed and built by me and ultimately aims to explore its feasibility for space launch missions by scaling it up to traditional sizes, modelling and extrapolating the data with MATLAB. Furthermore, the report will also investigate its scalability, compare theoretical data with the experimental ones for experimental validation, and potential optimizations for maximum thrust. The integration of data to MATLAB and both modelling and simulating for larger sized models will be essential to understand this type of thruster systems application in space launch, and together with theoretically discussing the variations that could be implemented into the model, this report will investigate if this type of electric propulsion, propulsion systems that use electric or magnetic fields to accelerate charged particles (ions) or plasma (Wikipedia, 2025), can be an alternative for traditionally used chemical propulsion. In the end, this report will discuss, and potentially challenge, the common view on electric propulsion and its unapplicable design for space launch.

Introduction

The exploration of space has always been driven by the need for efficient and reliable propulsion systems. Traditional chemical propulsion, particularly liquid propulsion, has been the cornerstone of space missions due to its high thrust capabilities and reliability. Liquid propulsion systems use chemical reactions to produce thrust, offering significant advantages such as high thrust-to-weight ratios and the ability to be throttled and restarted. However, these systems are limited by their relatively low specific impulse, which results in higher propellant consumption and increased mission costs.

In contrast, electric propulsion systems, including ionic thrusters, have emerged as a promising alternative for certain space applications. Electric propulsion uses electrical energy to accelerate propellants to high velocities, achieving much higher specific impulses compared to chemical propulsion. For instance, ionic thrusters can achieve specific impulses ranging from 1,500 to 10,000 seconds, significantly higher than the 300 to 450 seconds typical of liquid propulsion systems (Wikipedia, 2025). This efficiency translates to lower propellant mass requirements, making electric propulsion particularly advantageous for long-duration missions and deep-space exploration. Despite their lower thrust levels, typically in the range of millinewtons to a few newtons, electric propulsion systems can operate continuously for extended periods, providing a cumulative thrust that can significantly alter a spacecraft's trajectory over time (Karabeyoglu, 2019).

In this research paper, we are aiming to answer the research question of "How does the power-to-thrust ratio of an ionic thruster scale, and what are the feasibility limits of its application for space launch propulsion?". By investigating the relationship between power input and thrust output, we seek to understand the potential and constraints of ionic thrusters in achieving the necessary thrust for space launches. This study will contribute to the broader understanding of propulsion technologies and their future applications in space exploration and potentially will suggest to address the gaps in the research of efficient thrust.

II – Theory

Ionic propulsion systems (or electrohydrodynamic thrusters) operate by converting electrical energy into thrust through a sequence of physical processes:

- **Ion Creation:**
  High-voltage electrodes create a strong electric field near a sharp emitter. This field ionizes nearby gas molecules (typically ambient air or a chosen propellant) via corona discharge. In this process, electrons are stripped from the atoms or molecules, forming positively charged ions.

- **Acceleration:**
  Once created, these ions are accelerated by the applied electric field. The acceleration imparts kinetic energy to the ions, and because momentum is conserved, the device experiences a reactive thrust in the opposite direction. The acceleration mechanism is governed by the force exerted by the electric field on the ions.

- **Neutralization:**
  To prevent the buildup of a net charge—which would counteract further ion production and acceleration—the ion beam is typically neutralized. This is achieved by injecting electrons or by allowing free electrons from the ambient environment to recombine with the ion stream, thereby ensuring the overall charge balance of the exhaust (K. Holste, 2020).

Essential Equations

The performance and design of an ionic propulsion system are often characterized using a few key equations:

1. **Thrust Equation:**
   The basic expression for thrust (**F**) in any propulsion system is given by:

$$F = \dot{m} v_{ex}$$

Here, $\dot{m}$ is the mass flow rate of the ions (or exhaust), and v_{ex} is the effective exhaust velocity. In ionic thrusters, both parameters are typically much smaller than in conventional chemical engines.

Power-to-Thrust Relation:

The kinetic power imparted to the exhaust can be written as:

$$P = \frac{1}{2}\dot{m}{v_{ex}}^2$$

Dividing this by the thrust ($T = \dot{m}v_{ex}$) yields an ideal power-to-thrust ratio:

$$\frac{P}{T} = \frac{1}{2}v_{ex}$$

This relationship highlights that for a given exhaust velocity, the amount of power required per unit thrust increases linearly. In practice, ionic thrusters have very low v_{ex} (often fractions of a meter per second under atmospheric conditions), resulting in a high power-to-thrust ratio.

Specific Impulse:

Specific impulse (I_{sp})is a measure of propulsion efficiency, defined as the exhaust velocity normalized by the gravitational acceleration (Sforza, 2012):

$$I_{sp} = \frac{v_{ex}}{g_0}$$

III – Experiment

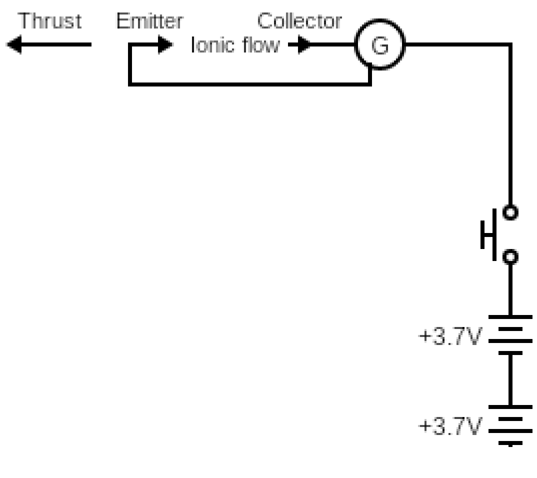

Figure 1

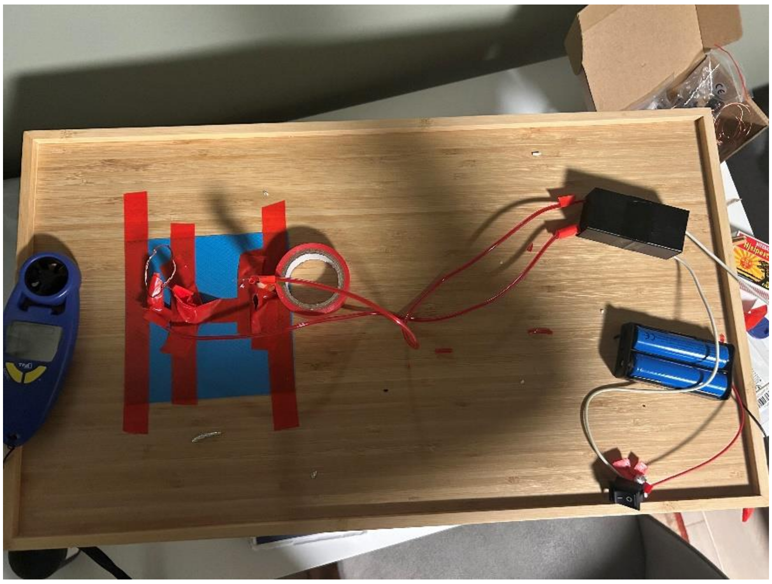

Figure 2

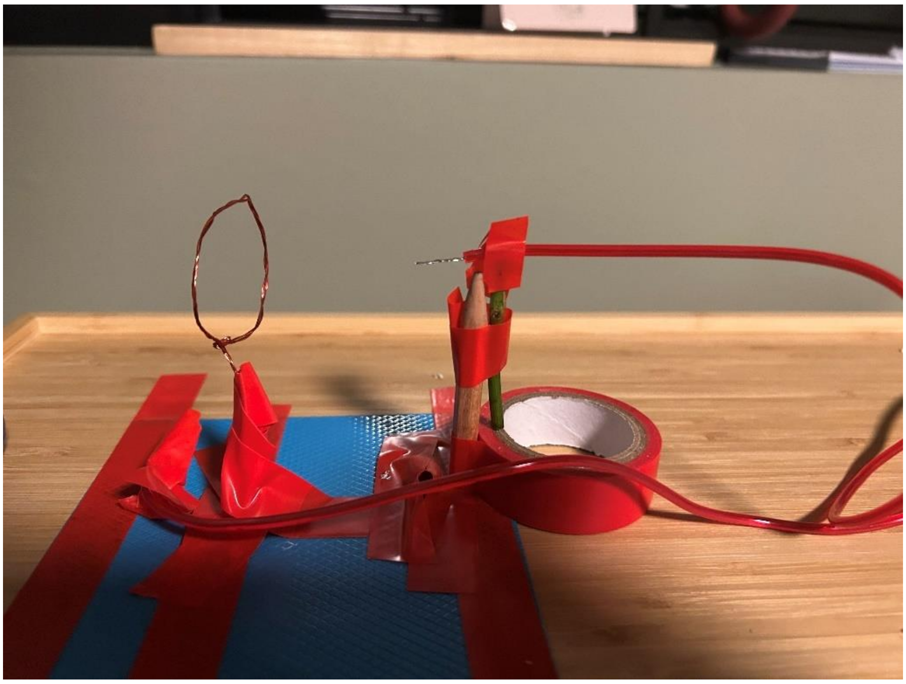

Figure 3

Figure 4

IV – Results

The record result measured from anemometer is 1.3 km/h.

V – Analysis

Electric (Ionic) Propulsion:

- **Low Exhaust Velocities:**
  In contrast, ionic thrusters accelerate ions to velocities that are often measured in fractions of a meter per second when operated in air, resulting in extremely low specific impulses (a few hundredths of a second under such conditions). Even if vacuum operation permits somewhat higher velocities, they remain orders of magnitude lower than those in chemical rockets.

- **Power Demand:**
  The high power-to-thrust ratio (e.g., roughly 170,000 W/N in my small-scale experiment) reflects the inherent challenge of generating significant thrust with low-mass ions. Although electric propulsion is fuel-efficient, its ability to produce high thrust is limited without significant power input.

- **Deep-Space Application vs. Launch:**
  While the low thrust of ionic systems restricts their use in launch applications, their efficiency (when scaled appropriately and operated in vacuum) makes them ideal for long-duration in-space maneuvers. In deep space, where continuous, low-thrust acceleration is advantageous, electric propulsion can provide efficient propulsion with minimal propellant consumption. Conversely, chemical rockets,

though powerful, are constrained by propellant mass and efficiency limits for long-duration missions.

VI – Conclusion & Evaluation

In contrast, the ionic wind generator's power-to-thrust ratio of approximately 170,000 W/N and a specific impulse of 0.037 seconds are orders of magnitude less efficient. This comparison underscores why ionic propulsion is currently limited to low-thrust applications such as satellite stationkeeping and in-space maneuvering rather than launch vehicles.

Summary of Findings

- **Thrust:** ~0.000113 N
- **Electrical Power:** ~19.24 W
- **Power-to-Thrust Ratio:** ~170,465 W/N
- **Specific Impulse:** ~0.037 s

These results are in line with literature values for small-scale ionic or EHD thrusters, which typically report power-to-thrust ratios in the range of 100,000–300,000 W/N and very low specific impulse values. In contrast, chemical propulsion systems are far more efficient in converting energy to thrust, making them indispensable for high-thrust applications like space launch.

VIII – Sources

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IX - Appendix