DESIGN AND EXPERIMENTAL EVALUATION OF AN ION ENGINE PROTOTYPE

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Abstract: *Ion propulsion, traditionally utilized to adjust satellite and space station trajectories, also demonstrates significant potential for aeronautical applications. This paper investigates the feasibility of an ionic motor designed to ionize ambient atmospheric air, eliminating the need for gases such as xenon or argon. The motor features a triangular geometry manufactured using 3D printing technology. Preliminary propulsion calculations are provided, focusing on determining the required voltage to achieve target airspeeds that yield sufficient thrust.*

These studies help to assemble a model that can propel its weight without using fossil fuel, opening up the possibility of giving up kerosene in the future by bringing new forms of propulsion structures simpler and more economical, introducing new possibilities!

Keywords: *Aerospace, Ionic engine, Generative Design, Additive Manufacturing*

1. INTRODUCTION

Ion propulsion, also referred to as electric propulsion, is a system in which electric current is used to ionize a propellant in order to generate thrust through high-velocity exhaust. This process significantly reduces the amount of propellant required compared to conventional chemical propulsion systems that rely on fossil fuels. By minimizing fuel consumption, the total mass of a spacecraft or launch vehicle can be substantially decreased, leading to lower launch costs and improved mission efficiency. [1]

Ion propulsion has been employed in space exploration since the 1960s and is increasingly being adopted for satellite systems and deep-space exploration missions, replacing traditional chemical thrusters in many applications. Among electric propulsion technologies, ion engines are considered top-tier in terms of performance indicators such as thrust efficiency, specific impulse, and operational longevity. These systems typically operate at voltages ranging from hundreds to thousands of volts, achieving specific impulses in the range of several thousand seconds while delivering low thrust. [1]

Common propellants for ion thrusters include inert gases such as xenon or argon. Xenon, in particular, is the preferred choice due to its ease of ionization, chemical inertness, and the practicality of storage in liquefied form, which allows for more efficient transportation into space. [1]

In a typical ion engine, xenon gas is ionized to form plasma, which is then accelerated through an electric field to produce thrust. While the thrust produced is relatively low compared to chemical propulsion systems, the efficiency is significantly higher, enabling spacecraft to operate continuously for thousands of hours using a minimal amount of propellant. [1]

Objective of the Research

The primary objective of this study is the development of a functional prototype and the experimental evaluation of its performance under atmospheric conditions, without the use of fossil fuels or noble gases.

Electric Propulsion General Principle

Electric propulsion achieves high specific impulses by accelerating electrically charged particles to very high velocities. These charged particles are created through the ionization of a gas — in this case, atmospheric air. The ionization process produces both ions and free electrons, forming what is known as plasma. When subjected to a high-voltage electric field, the plasma particles are accelerated toward neutral molecules, transferring momentum and generating what is known as ionic wind (also referred to as electrohydrodynamic thrust). [1,2]

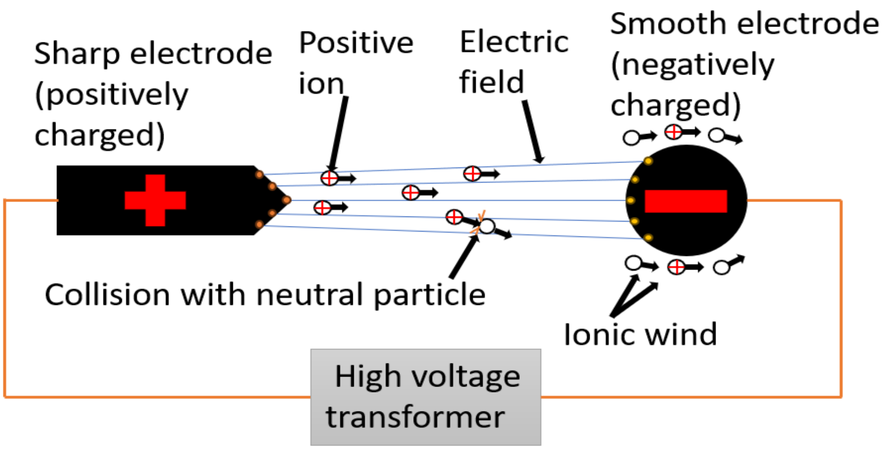

FIG. 1 Schematic representation of the electric propulsion phenomenon

2. CLASSIFICATION OF ELECTRIC PROPULSION SYSTEMS

Electric propulsion systems are generally classified based on the method by which they accelerate particles. The three main categories are:

- Electrostatic
- Electromagnetic
- Electrothermal

2.1 Arcjet Thrusters (Electrothermal)

An arcjet thruster is a type of electrothermal propulsion system that heats the propellant by passing it through a high-voltage electric arc, located upstream of the nozzle. Although plasma is formed in this process, the level of ionization is low, and the resulting plasma contributes minimally to the exhaust velocity. The specific impulse is typically limited to below 700 seconds when using storable propellants. [1]

2.2 Ion Thrusters (Electrostatic)

Ion thrusters utilize various techniques to ionize a significant portion of the propellant gas. These systems use electrostatic grids to extract the positively charged ions from the plasma and accelerate them to very high velocities, often exceeding 10 kV. Ion thrusters are among the most efficient electric propulsion systems, achieving efficiencies of 60% to over 80% and specific impulses ranging from 2,000 to 10,000 seconds. [1]

2.3 Hall Effect Thrusters (Electrostatic)

Hall thrusters use a unique configuration involving a perpendicular electric and magnetic field to create and accelerate plasma.

The electric field accelerates ions, while the magnetic field inhibits electron motion in the direction of the electric field, maintaining charge separation and preventing electrical shorting. Although Hall thrusters typically have lower efficiency and specific impulse than ion thrusters, they produce higher thrust at the same power input and are simpler to construct and operate, requiring fewer power supply systems. [1]

3. PROTOTYPE MANUFACTURING PROCESS

The prototype was manufactured using additive manufacturing, more commonly known as 3D printing, with equipment provided by the faculty laboratory.

Additive manufacturing is a layer-by-layer fabrication technology, where physical components or assemblies are produced from a digital 3D model. This 3D model is created using Computer-Aided Design (CAD) software. Common CAD platforms used for modeling include CATIA, CREO, Fusion 360, and SolidWorks, among others.

During the printing process, the printer deposits successive layers of material, each representing a horizontal cross-section of the final part. The layer thickness can be adjusted: thinner layers result in higher surface quality but increase manufacturing time, while thicker layers reduce printing time at the cost of precision and finish. [3]

Although the additive manufacturing process may seem complex, it generally consists of eight straightforward steps:

1. 3D Model Generation

All parts to be manufactured via 3D printing must first be designed using CAD software. The model must incorporate the exact dimensions required and must fit within the build volume of the chosen 3D printer. Alternatively, existing components can be 3D scanned to generate editable digital models for replication or modification. [3]

2. Saving the File as STL

Once the design is finalized, the model must be exported in STL format or another format compatible with the slicing software used by the 3D printer. [3]

3. Importing the STL File into the Printer Software

The STL file is then loaded into the printer's software interface, where the object is positioned on the print bed. At this stage, the model can be rotated, scaled, or otherwise adjusted to ensure proper orientation and fit. [3]

4. Printer Configuration and Calibration

The next step involves selecting the appropriate printing parameters, including:

- Material type and extrusion temperature
- Bed temperature
- Layer height
- Print speed
- Quality settings
- Support structures (if needed)

If the printer has been moved or unused for an extended period, recalibration is recommended to ensure optimal print quality. [3]

5. Printing the Part

The printing process is automated, with the printer executing the job based on the predefined parameters. Human supervision is recommended to detect any malfunctions or deviations. [3]

6. Removing the Printed Part

After completion, the part is carefully removed from the print bed. In some cases, the print bed may need to be detached from the machine. A spatula or scraper can help detach the part without damage. [3]

7. Post-Processing

Post-processing may include:

- Removal of support structures
- Trimming excess filament residue
- Surface smoothing using sandpaper
- Painting or coating for improved aesthetics or functionality

8. Final Component

The resulting part can be used as-is, or integrated with other 3D-printed components, mechanical parts, or electronic elements for full assembly. [3]

For this prototype, the Zortrax M200 Plus 3D printer was used.

Table 1. Specifications of the Zortrax M200 Plus Printer [4]

Feature	Specification
Build Volume	200 × 200 × 180 mm (heated bed)
Nozzle Diameter	0.4 mm (standard); 0.3 mm; 0.6 mm
Connectivity	Wi-Fi, USB, Ethernet
Display	4” IPS, 800 × 480 resolution
Filament Diameter	1.75 mm
Maximum Temperature	290°C (nozzle), 105°C (heated bed)
Power Supply	110 V / 240 V

FIG. 2 Zortrax M200 Plus 3D Printer

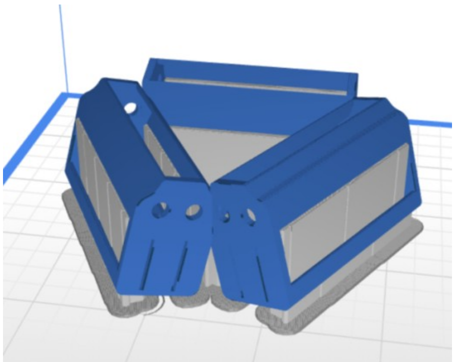

FIG. 3 Fully Printed 3D Model (100%)

After removing the printed model from the 3D printer, the support structures must be detached. For this operation, we used a pair of pliers to carefully remove the supports without damaging the model.

FIG. 4 Printed 3D Model (with supports) **FIG. 5** Cleaned Model (supports removed)

Electrode Preparation

For the anode components, we selected copper tubes with a 6 mm outer diameter. Since the design requires six pieces, we purchased a 1-meter-long tube, and cut it into 6 segments of 8.5 cm each using a standard pipe cutter.

FIG. 6 Marking the copper tube for cutting

FIG. 7 Final copper anode segments

For the cathode, we used a sheet of aluminum measuring 120 × 1000 × 0.8 mm. We cut six strips from this sheet, each 9 cm long and 1 cm wide. To improve ionization efficiency, small teeth were cut on one side of each strip using metal shears.

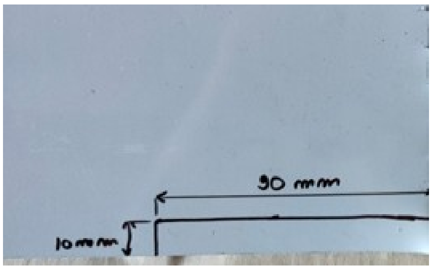

FIG. 8 Cutting layout for one cathode strip

FIG. 9 Completed set of six aluminum cathodes

3.1 Motor Power Supply

The motor requires two electrodes: the cathode, which emits electrons, and the anode, which collects them and neutralizes the charge, allowing only the ionic wind (neutral air flow) to exit the system.

For the power supply system of the ion propulsion unit, we used:

- A battery pack (DC power source) to ensure portability and eliminate the need for a direct AC power connection.
- A high-voltage transformer to generate the voltage required for electrode ionization.

These two components are connected in series, where the battery provides current, and the transformer boosts the voltage to the operational range required by the ion motor.

Table 2. Technical Specifications of the Battery Pack

Component	Voltage (V)	Current (A)	Capacity (mAh)	Weight (g)
LG Battery	3.7	10	3200	47

Table 3. Technical Specifications of the High-Voltage Transformer

Component	Output Voltage (kV)	Input Voltage (VDC)	Current (A)	Weight (g)

Transformer	800–1000	3–6	— (not specified)	53

FIG. 10 Battery Pack (LG 3.7V, 3200 mAh)

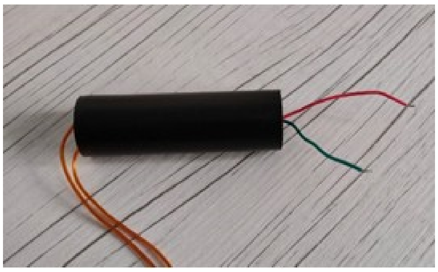

FIG. 11 High-Voltage Transformer (800–1000 kv)

The electrical configuration consists of a battery connected to a high-voltage transformer, which supplies the required potential difference between the cathode and anode of the ion propulsion system. This configuration enables the ionization of atmospheric air and the generation of ionic wind through accelerated charged particles.

The schematic in Figure 12 illustrates the basic wiring layout, including the power supply components, safety considerations, and electrode configuration.

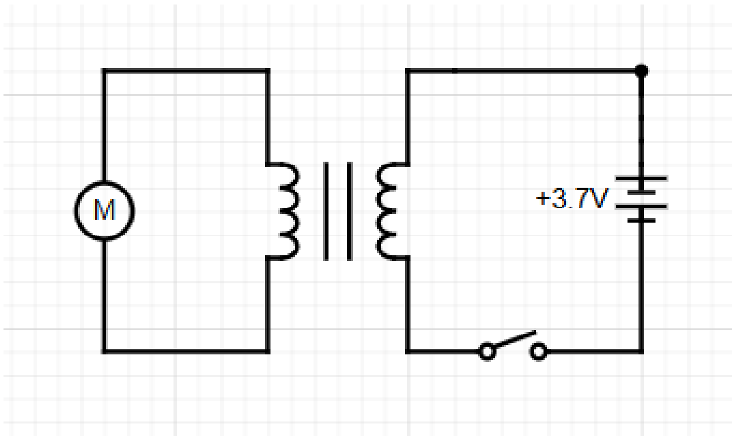

FIG. 12 Electrical Wiring Diagram for the Ion Propulsion System

CONCLUSIONS

Through the fabrication and testing of this prototype, we demonstrated that the phenomenon of ionic wind generation can be reproduced in atmospheric conditions using a relatively simple setup and without any form of propellant, relying solely on ambient air.

One of the main challenges encountered was identifying a sufficiently powerful power source capable of sustaining the high voltage required to initiate plasma formation. A second major obstacle was determining the optimal distance between the electrodes — specifically, the maximum proximity at which plasma is sustained without causing electric discharge (arcing). After multiple experiments and configuration trials, it was concluded that the minimum safe gap between electrodes is approximately 8 mm; reducing this distance further results in uncontrolled electric discharge.

Despite the low thrust generated, we were able to observe and feel the presence of a weak but perceptible ionic wind. Although we currently lack the instrumentation (e.g., an anemometer) to quantify the airflow precisely, the experiment validates the concept and lays the foundation for future improvements.

Potential areas for further development include:

- Enhancing the thrust-to-power ratio
- Improving electrode geometry
- Introducing diagnostic tools for quantitative performance analysis

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