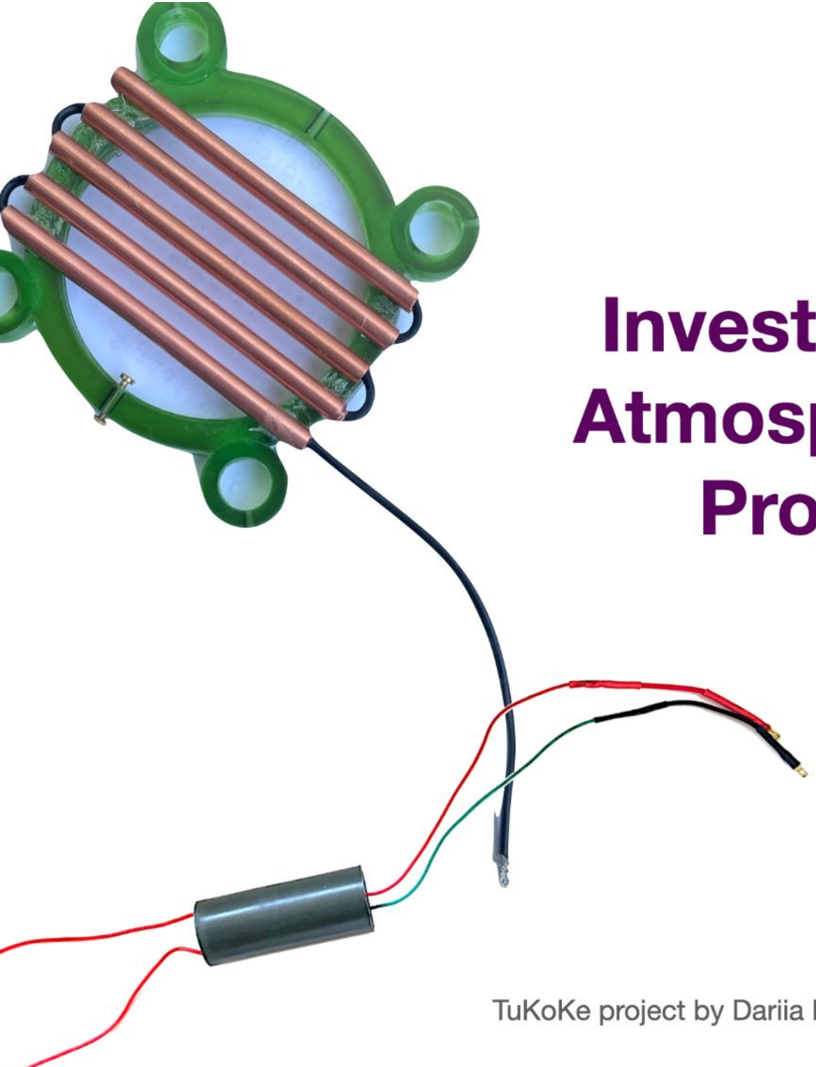
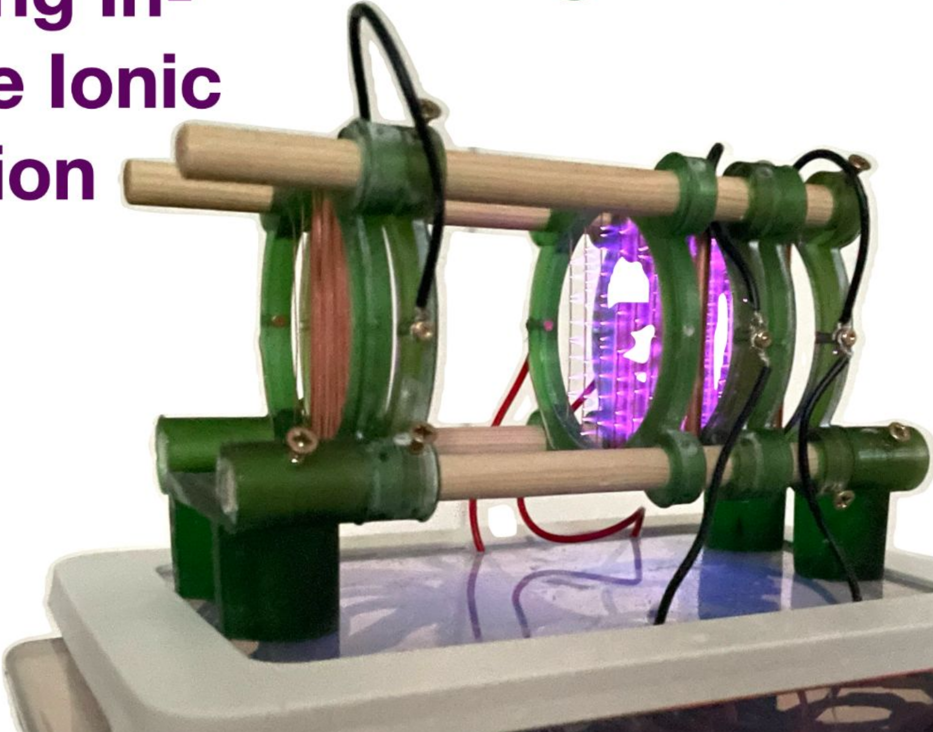


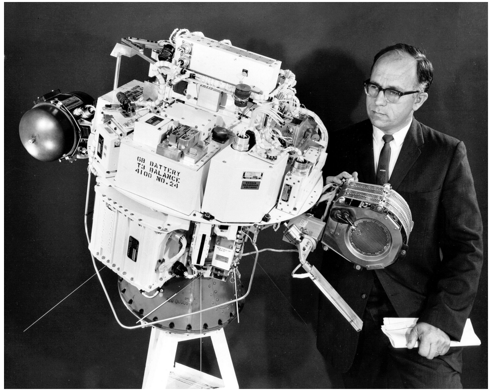
Investigating In-Atmosphere Ionic Propulsion



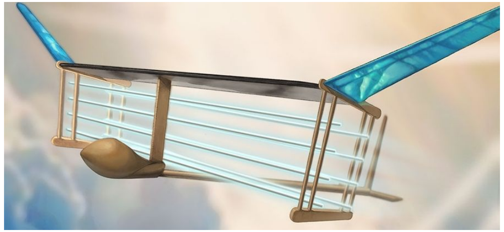
TuKoKe project by Dariia Korsun

Introduction to ionic propulsion

- Basic principle: ions accelerated in an electric (or magnetic) field.
- First described in 1911 and built in 1959.
- Used to propel spacecraft, but increasingly relevant for atmospheric propulsion as a possible future alternative to combustion engines.
- This project involved constructing and testing an ion thruster.



The SERT-1 probe was the first spacecraft to utilize ionic propulsion in 1964. *Image: NASA*



The first ever plane powered by ionic wind was built by MIT engineers in 2018. It flew a distance of 60 meters. *Image: Christine Y. He*

Ionic vs. chemical propulsion

- No combustion -> no CO_2
- No moving parts -> less subject to failure and easier to maintain
- High specific impulse = high efficiency

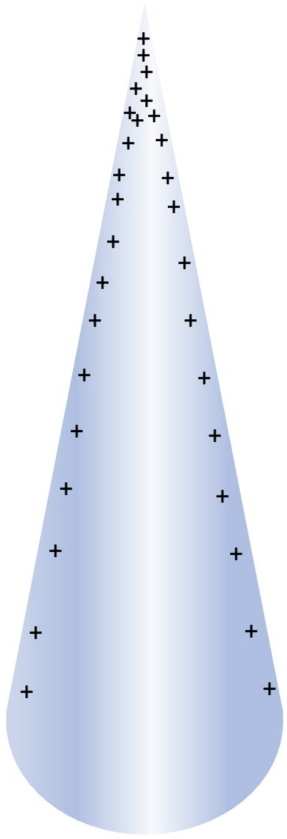
- Low thrust = (currently) ineffective for larger aircraft
- In case of atmospheric operation, highly dependent on altitude, humidity, air density, temperature and pressure.
- Ionized air can go on to form nitrous oxides (greenhouse gases)

Theoretical background

A ‘grid’ consisting of two electrodes is connected to a high voltage power source.

Air at the anode (called the **emitter**) is turned into plasma by field ionization. The ions are accelerated toward the cathode (**collector**). On their way they lose energy by colliding with neutral particles. In fact, most of the so-called ‘ionic’ or ‘electric wind’ consists of neutral molecules.

The electric field is strong enough to ionize air because the electrodes are asymmetric. The emitter has a sharp edge, leading to a higher concentration of charges.



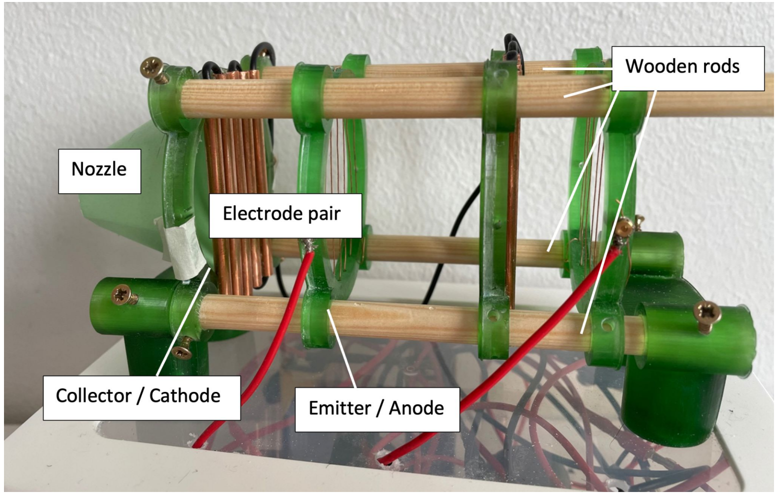
Unequal charge distribution around a sharp edge.
Image: own work

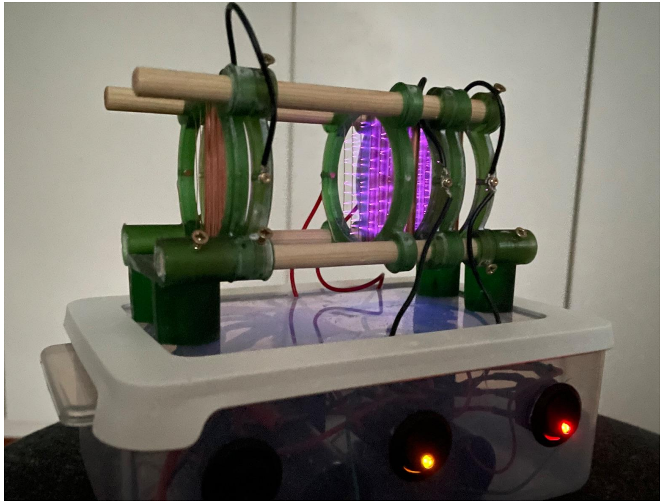
Construction

The ion thruster in this experiment relies on field ionization, hence the anode/emitter is a grid of thin wires and the cathode/collector is a grid of tubes.

High voltage is provided by a boost converter, which is connected to a power supply.

DC input is necessary to operate the ion thruster because the polarity of the electrodes must stay the same so that ions always move in one direction.





Experiment

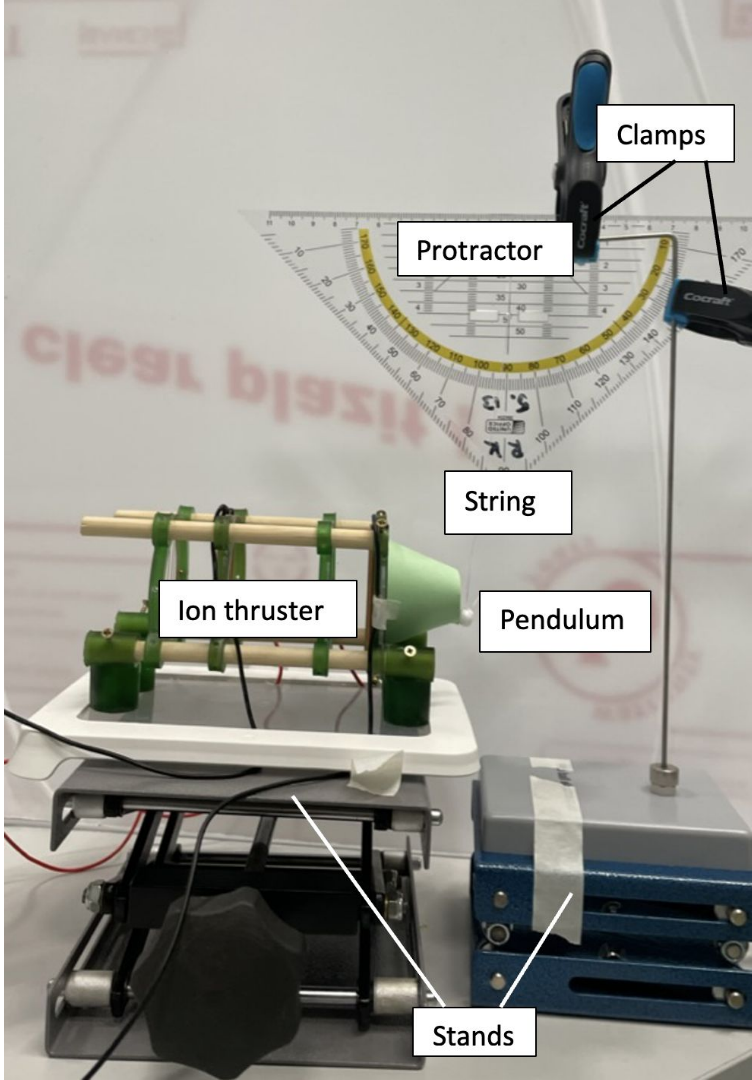
Research question: *How does the distance between the electrodes of an ion thruster affect its output thrust?*

Independent variable: distance between electrodes

Dependent variable: output thrust

Controlled variables: everything else that might affect thrust; namely, atmospheric conditions, input voltage, electrode configuration and material, air movement in the room, etc.

This research question was chosen because electrode separation - thrust relationships have been researched less than voltage - thrust and current - thrust relationships.



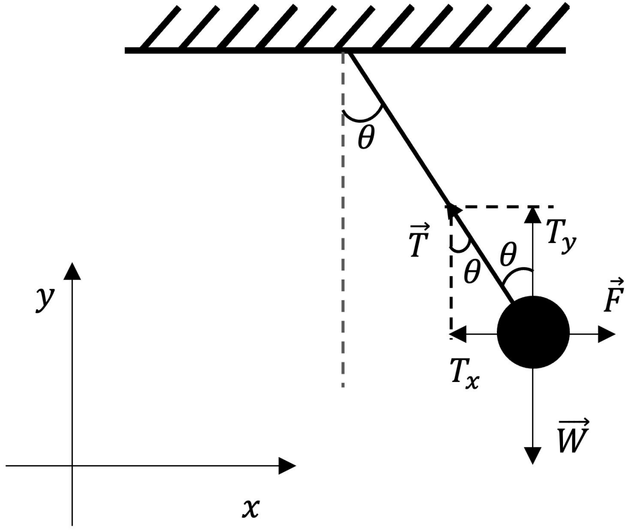
Experiment

The inclination of a light pendulum from equilibrium was used for calculating thrust. Each measurement was repeated five times for accuracy.

A formula was also derived theoretically to describe the relationship between thrust and electron separation. The formula was based on previous research by Townsend (1914) and Cooperman (1960) on the relationship between corona current and corona onset voltage.

Mathematical model, where ***d*** is electrode separation:

$$F = C_0 U(U - U_0)(1 - C_D \frac{S}{A}) \cdot \frac{1}{d}$$

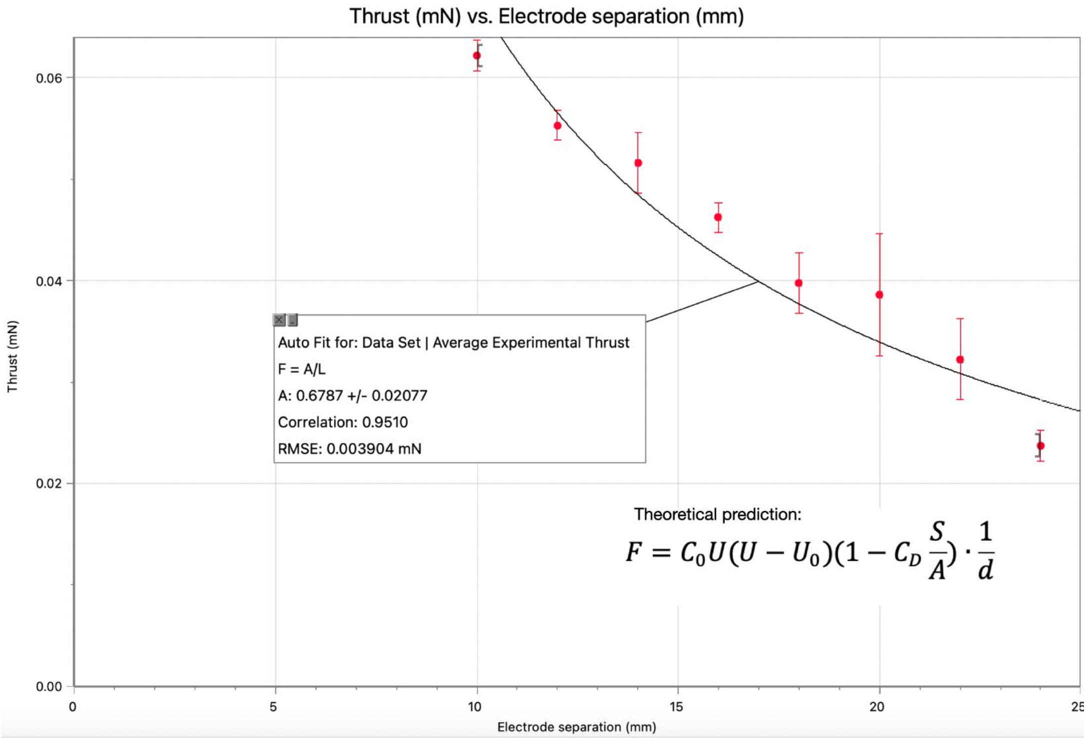


Experimental formula based on the free body diagram above:

$$F = mg\ tan\theta$$

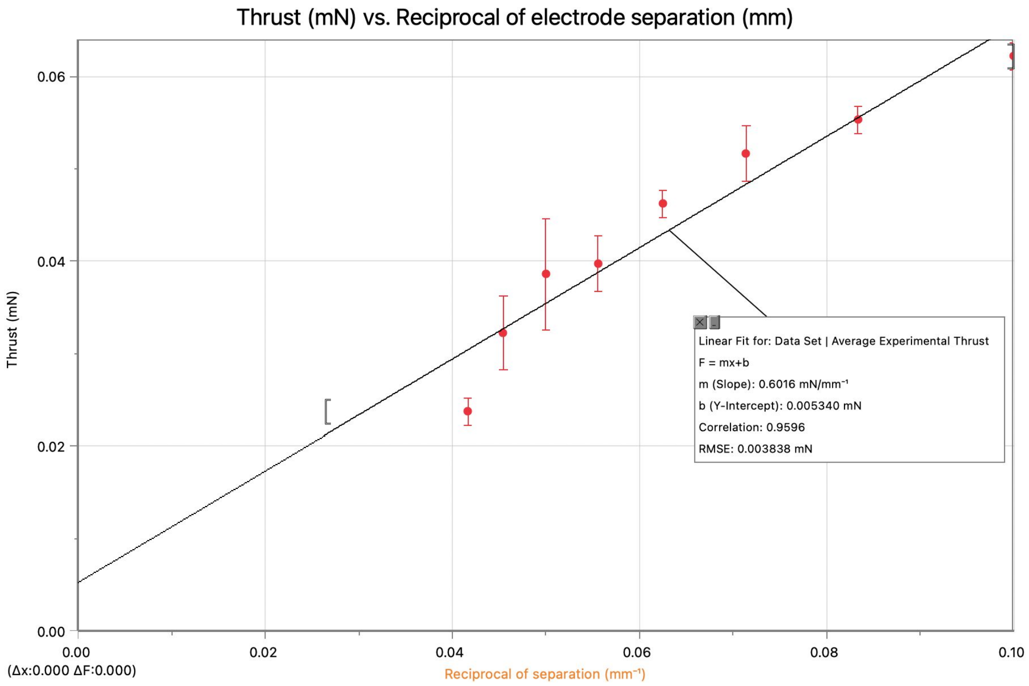
The mass ***m*** of the pendulum is known and the angle is measured.

Results



- As electrode separation increases, output thrust decreases.
- The fitted curve is based on the theoretically predicted relationship.
- Data points are average values.
- Error bars are based on the difference between the highest and lowest measured value.

Results



- Another way to present the data to get a linear graph is by graphing thrust against the reciprocal of electrode separation.
- The linear fit is satisfactory (correlation 0.9596), but it looks like a curve fit would be more appropriate.
- Nevertheless, I kept the existing best fits because they have a theoretical justification.

Analysis

The experiment was successful in answering the research question.

The mathematical model is not a perfect fit, which is to be expected since a number of assumptions were made, such as one-dimensional ion movement, uniform charge density, negligible ion weight and others.

The highest thrust was 63 mN, at a 10.0 mm distance between the electrodes. This is significantly lower than the output of ion engines used in spacecraft (around 5 N) or a similar atmospheric thrusted constructed by Wilson et al (2009), which produced a thrust of 0.02 N at an electrode separation of 9.5 mm.

This can be explained by differences in design, since the engine in this project is a prototype designed for investigation and demonstration rather than maximal efficiency in flight.

Evaluation

There were several factors that affected the accuracy of the data:

1. **Air composition** changed as air was ionized and new molecules were formed. To minimize this, the engine was operated with breaks.
2. **Air temperature** was affected by corona discharge. As air heats up, its molecules move faster, which decreases the engine's efficiency. (Sathpathy et al. 2023)
3. **Electrode shape** most likely did not stay constant due to high temperatures associated with corona discharge, though no melting was observed.
4. **Limitations in the methodology**, mainly related to measurements made with a protractor, which had to be at eye level at all times. It would have been beneficial to have a camera on a tripod recording protractor readings.

Conclusion

This project aimed to answer the following research question:

How does the distance between the electrodes of an ion thruster affect its output thrust?

The question was approached theoretically and experimentally. The answer according to theory and experimental data is that the output thrust of an ion engine decreases as electrode separation increases.

This is in line with the mathematical model that was derived to predict the relationship; however, the data suggests that the model is only applicable under ideal conditions and more research is needed to either add new variables or implement a correction factor.

Next steps

For ionic propulsion to power real aircraft, I propose that the following is done:

- More research into the effect of air composition on the operation of ionic engines. This is important because air composition changes with altitude and the engine has to operate during takeoff, cruise and landing.
- Weight optimization: using lighter materials so that flight can be achieved.
- Energy input: experimenting with power sources (batteries or solar energy).
- Testing different air gap sizes and electrode configurations.
- Testing ways to combine ion propulsion with other propulsion methods.