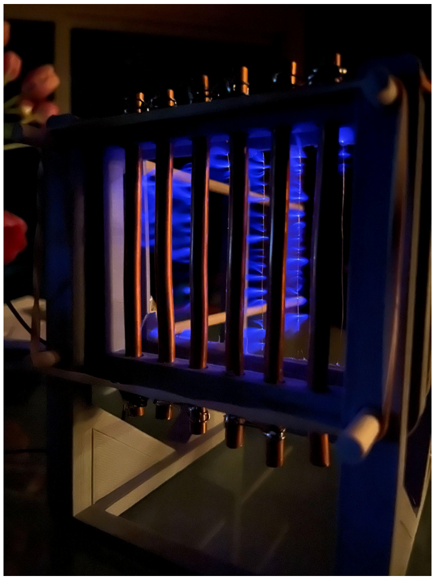


Electrohydrodynamic (Ionic) Thruster Design

Below is a brief overview of the current EHD thruster and high voltage power converter design. The system is currently operational and lab testing is underway.

An EHD thruster is a device which creates a flow of air (ionic wind) through the electrostatic forces between bodies of different curvature and voltage potential (eg. A thin wire and large tube). Figure 1 to the left shows the EHD thruster in operation. This video shows my thruster in operation as well. The purple glow is the plasma created via corona discharge. This video I made explains the thruster working principle.

Figure 1 (left): One of my EHD thrusters in operation.

Research Focus

The focus of this research is to determine the relationship between the distance between electrode pairs and the thrust produced by the thruster. A large spatial presence is a weakness of this technology, and thus, optimizing the thrust per unit volume is key. Here, we explore this issue with regards to electrode pair interaction. *Graph 1* shows the preliminary results for this relationship, suggesting an optimal electrode pair spacing of between 2 to 4 cm.

Thruster Construction:

A 3D printed structure (*Figure 3*), holds up the cathode and anode. The cathode (emitter) is a high gauge wire of 34.5 AWG and the anode (collector) is a 6.35mm copper tube, preventing unwanted corona discharges (due to its corona inception voltage of around 70kV). The EHD thruster takes 50kV DC as its input, provided by a custom built high voltage power converter.

High Voltage Power Converter (HVPC):
Safe Operation Guidelines Document

The fully custom built HVPC, which steps up 30VDC to 50kVDC. 30VDC from a 5A power pack powers a 555 timer circuit which outputs a 13kHz square wave with 50% duty cycle. This is fed to a power MOSFET, which pulses power to the primary of a custom made alternating current flyback transformer. The output of the flyback is around 3-4kV ac. The flyback supplies a 4 stage half bridge

Cockcroft-Walton voltage multiplier, which steps the voltage up to 50kV. The voltage multiplier, and later the transformer, is kept in oil in order to prevent arcing. The IRFP260N MOSFET is attached to a 2x3cm finned heat sink in order to dissipate heat and improve efficiency. Please refer to *Figures 2, 4 and 5* below for more information about HVPC design.

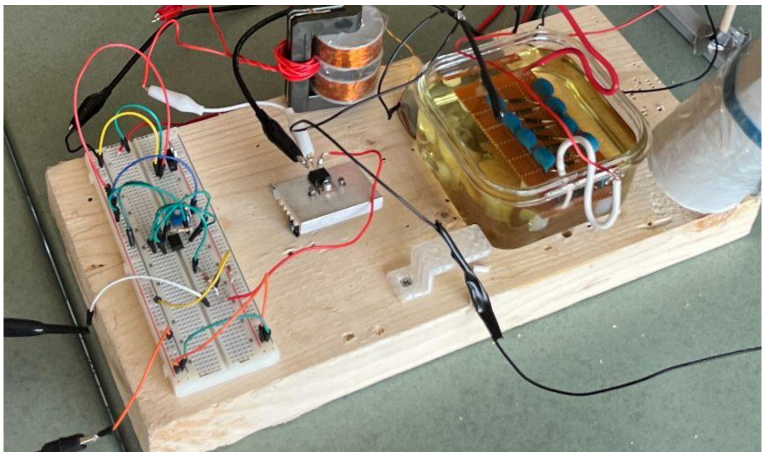


Figure 2: Image of the HVPC V1. V2 uses a larger power MOSFET (IRFP260N) and a transformer submerged in oil.

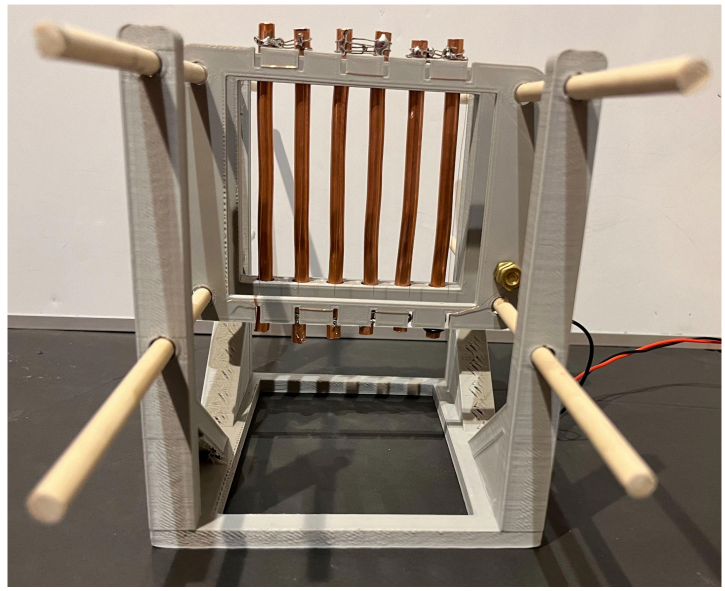
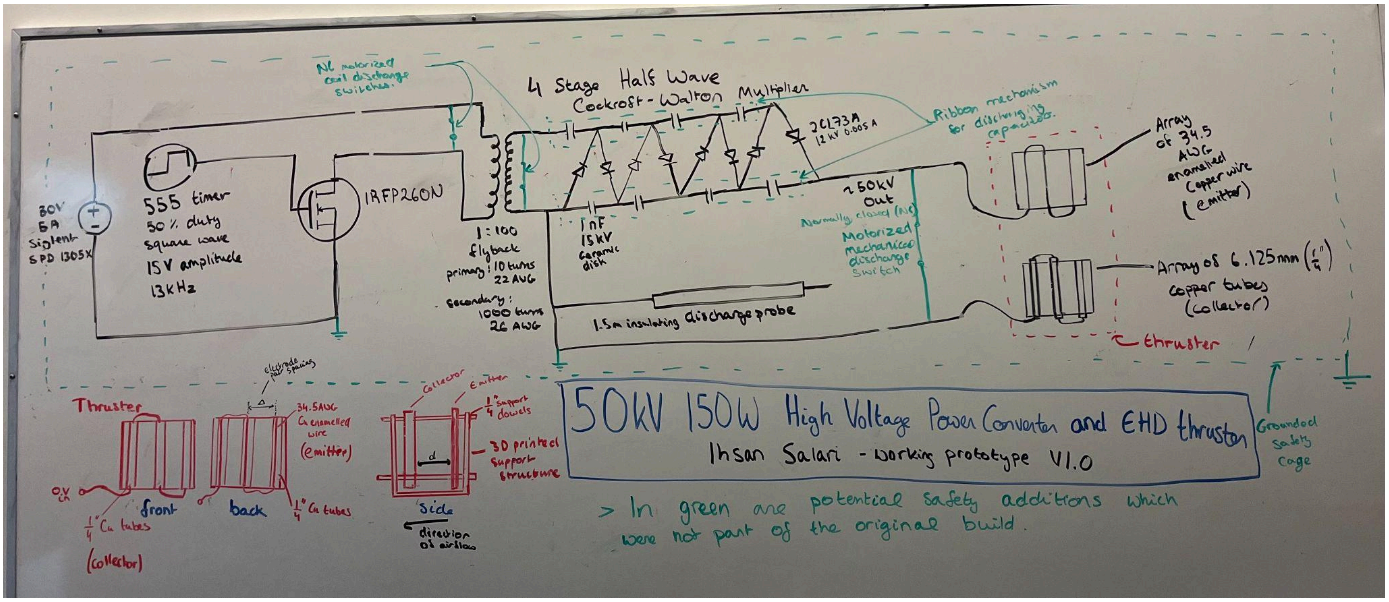


Figure 3 - Image of EHD thruster Design



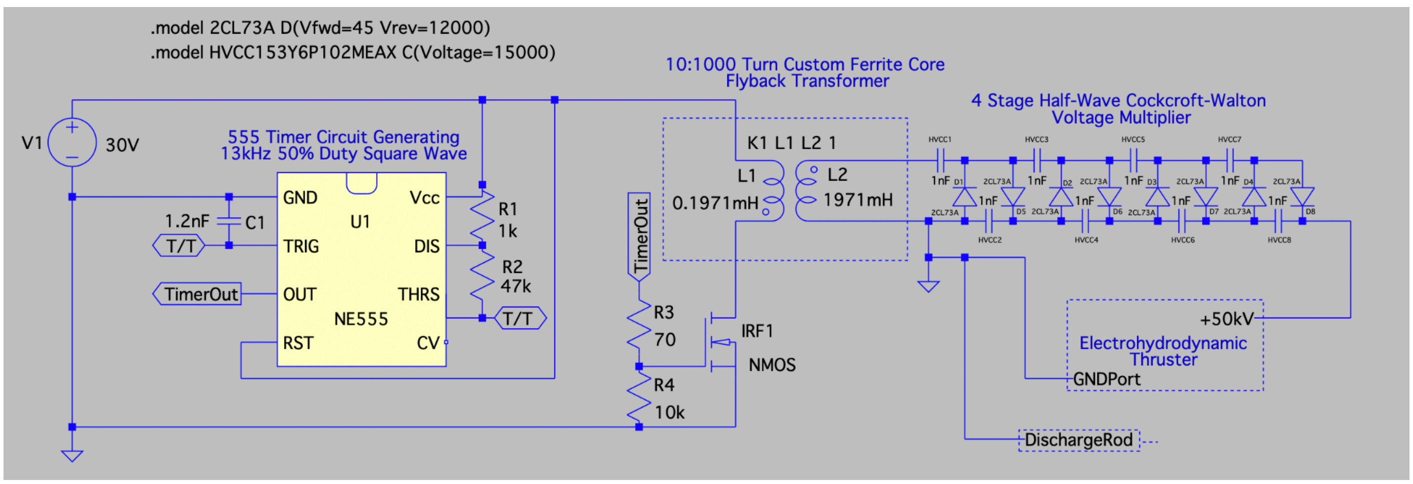


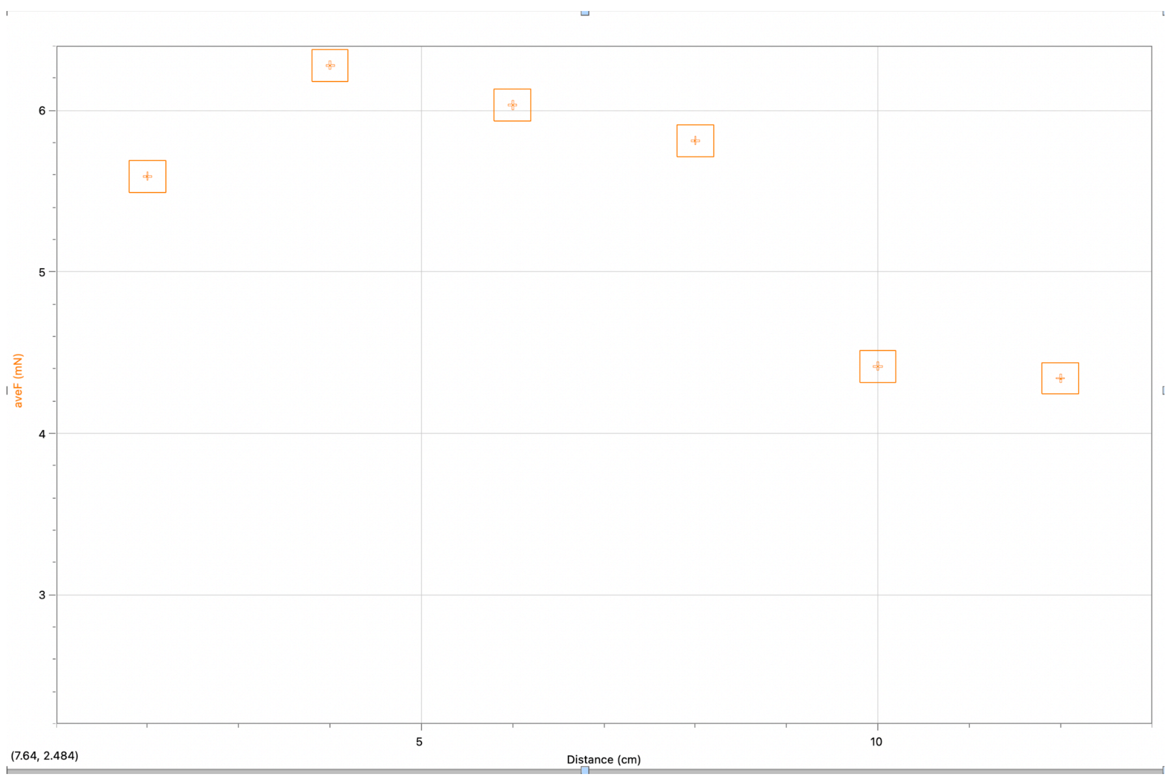
Figure 4 (top) and 5 (below): System Schematics. The green writing outlines potential safety modifications to the original design.

Building Process

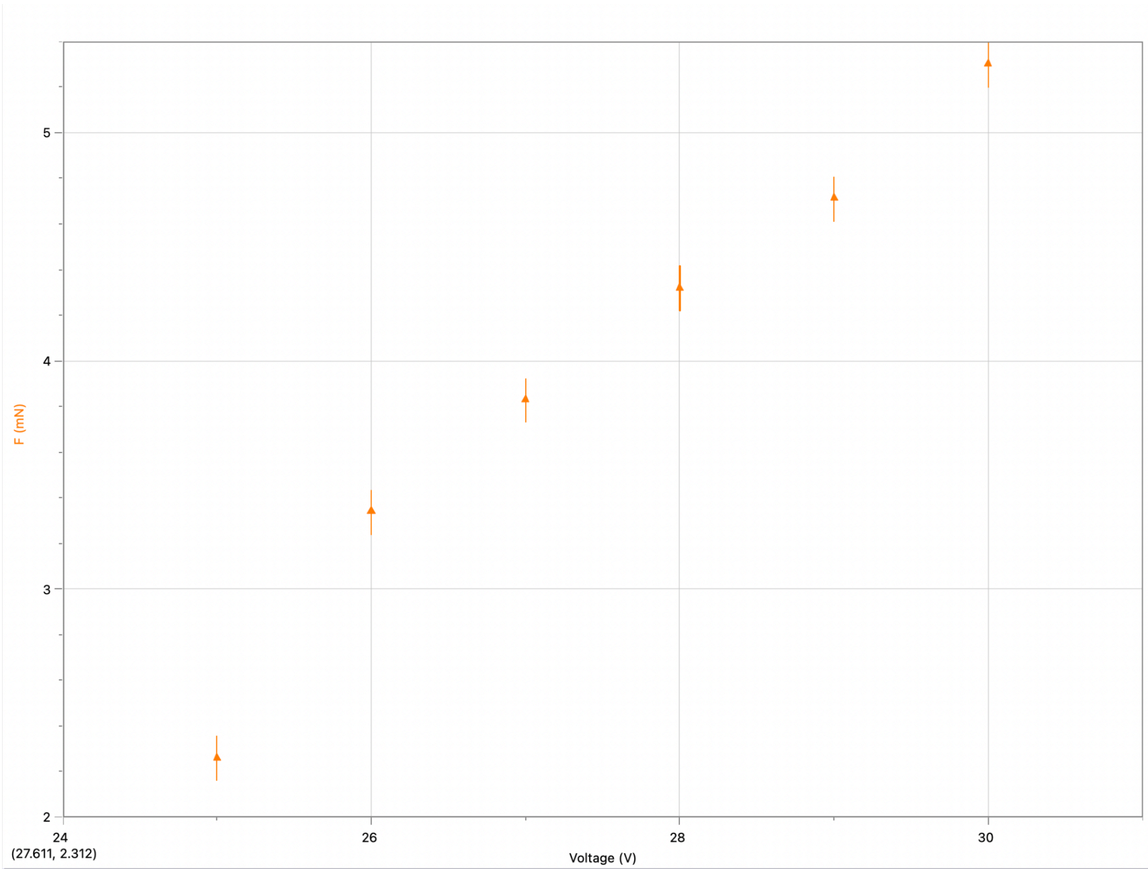
The first step was understanding common high voltage power converter topologies and drivers, which I extensively researched. I looked into three main areas: transformers, resonant inverters and oscillator driver circuits, and voltage multipliers. I then ran many simulations in LTSpice before testing prototypes. My first version of the high voltage power converter (HVPC) consisted of a mains transformer which I wound to step up the voltage to a few kV. However, this design did not work, popping the breaker due to too low of an impedance and wrong transformer core material choice. I then pivoted and built a DC flyback converter based topology, which successfully generated a few kV. Finally, I wound my own AC flyback transformer and built a 4 stage half bridge Cockcroft-Walton voltage multiplier. The thruster construction was quite straightforward and I built many iterations of the electrode spacing layout to obtain the highest wind speed possible. I then built the final test structure which I used to vary the electrode pair spacing and experimentally determine the optimal spacing, as showcased in my research. Switching out the small MOSFET with a larger IRFP260N power MOSFET submerged in water for better cooling drastically increased the max power of the thruster. The most thrust I generated was with a large electrode pair spacing of 10cm and totaled 4g of thrust, or about 39mN. Upon reaching out to Caltech, University of Waterloo and University of British Columbia professors in the field, I received very supportive comments, despite the fact that no direct technical advice could be given due to liability concerns.

Preliminary Results and Experimental Setup

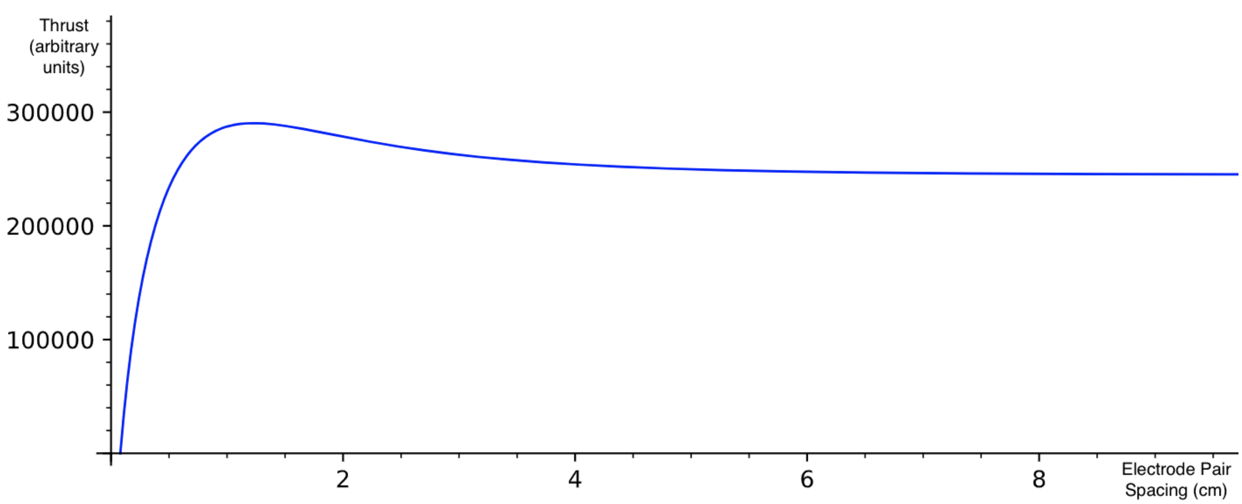
Graph 1: Distance Between Electrode Pairs (cm/±0.1) vs Thrust Produced (mN)



Graph 2: HVPC Input Voltage (V/±0.001) versus Thrust Produced (mN)



Graph 3: Thrust versus Electrode Pair Spacing. This relationship was derived in the theory of my research paper and confirms the existence of an optimal electrode pair spacing.



Research Paper Abstract - Available in Research Supplement

Previous work has shown electrohydrodynamic (EHD) propulsion methods to be a potential alternative to conventional means of aircraft propulsion. This technology emits no greenhouse gasses, is quieter than conventional propulsion methods, and has been shown to have a similar thrust to power ratio. However, spatial demands limit the widespread adoption of EHD thrusters. In this paper, we address spatial optimization of single stage EHD thrusters consisting of two wire-to-cylinder electrode pairs. We confirm the existence of an optimal electrode pair spacing for this thruster geometry. Previous efforts by Gilmore and Barrett (MIT) have estimated a maximum thrust per unit area of $3.3Nm^{-1}$. We extend their work by deriving and calculating the optimal electrode pair spacing with respect to the inter-electrode distance d. The findings presented in this paper will enable the construction of more spatially efficient EHD thrusters, allowing this technology to become a viable option for an increased number of applications.

References

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[2] http://dx.doi.org/10.1109/compel.2017.8013315 (Design and implementation of a lightweight high-voltage power converter for electro-aerodynamic propulsion

[3] https://royalsocietypublishing.org/doi/epdf/10.1098/rspa.2014.0912 (Electrohydrodynamic thrust density using positive corona-induced ionic winds for in-atmosphere propulsion)

[4] https://royalsocietypublishing.org/doi/epdf/10.1098/rspa.2012.0623 (On the performance of electrohydrodynamic propulsion)