Personal Statement

Perhaps the greatest moment of certainty that I have ever experienced came to me in the middle of the night, 4000 miles from home, while sitting alone on the balcony of an Airbnb overlooking the Toulouse skyline. I remember the moment vividly, because it was the night before my 6 am flight home, and I didn't even bother trying to sleep. For the past week, I had been immersed in a fully funded trip to the International Electric Propulsion Conference, where I learned about the very forefront of electric propulsion research from leading experts in the field. My days were spent attending talks and discussing ambitious ideas with brilliantly creative students, while my evenings were spent outside in a summer breeze that felt saturated with inspiration. On that last night, after everyone else had gone to bed, I stayed outside to watch satellites soar above the Kármán line, and suddenly space didn't seem so far away.

I realized during my trip that the motivation for my research was beginning to shift from a mere interest in space plasmas and particle dynamics toward a directed intent to open a door to the cosmos. I wanted to learn everything I could and use that knowledge to develop a better and more efficient thruster, leveraging my experience in particle physics and fusion reactors along the way. I spent just about every minute between talks writing down new ideas, skimming through papers, and crunching numbers. I identified flaws in my current setup, and came up with novel solutions for multiple issues, some of which involved using the very diagnostic methods I learned about during the conference. In fact, much of my project narrative follows directly from these original ideas.

My research at Penn State began during my second year at The Pennsylvania State University, when I approached Dr. Sven Bilén of the Aerospace Engineering Department with a design for a fusor that I attempted to build in high school out of an interest in accelerators. Though a broken collarbone, a subsequent pandemic, and food poisoning caused some academic difficulties during my transition into college, Dr. Bilén allowed me to join his Systems Design Lab to work on the fusor project. I began construction in September 2021, working with a graduate student named Anže Uršič in a small lab under a basement stairwell, with no official funding. This limitation forced me to become highly resourceful with lab materials, ultimately building the reactor almost entirely out of spare parts by rewiring control pins between previously incompatible devices and even shorting the floating filament of a high-voltage X-Ray power supply scavenged from eBay. I learned how to stay patient, spending weeks teaching myself a decades-old DeviceNet communication protocol, and helped Anže develop a remote interface in LabVIEW, complete with pressure, voltage, and flow rate control. A current readout and live view of the interior of the reactor allowed us to actively monitor the system. We achieved detectable fusion at 28 kV, 10 mA, and 15 mTorr in October 2022. This project embodies why I find Penn State to be the ideal fit for my graduate work; Though a project like nuclear fusion was highly ambitious, Dr. Bilén was willing to fully support us, navigating all of the logistics and red tape necessary to get the project approved with the University, who gave us the chance to let Environmental Health and Safety evaluate our setup, guide us through the radiation certification process, and even provide staff and resources to monitor radiation levels during our test runs. Some of the concepts I propose in my project narrative involve high voltages and secondary fusion, so it helps to already have the foundational support and infrastructure in place to ensure that my work takes off successfully.

Following multiple successful runs, I initiated a research project under Dr. Bilén's Space Propulsion and Environments Lab to modify the system and investigate the performance of an

Inertial Electrostatic Confinement thruster equipped with concentric helical electrodes and an internal gas feedthrough. I modelled the thruster in AutoCAD, then ran it through magnetic field simulations in COMSOL Multiphysics to study the effects of various cathode geometries. Still without significant funding, I fabricated the device from scratch using only a quartz glass tube and materials I found in a closet. After installing the thruster, I measured Paschen curves for various gases, measured current-voltage characteristics, and observed beam divergence. I used a Gauss meter to measure the magnetic fields between various ring magnets I found in a hobby shop and used them to induce beam curvature, extrapolating the velocity of the electron beam from its radius. Finally, I coded a LabVIEW script to conduct a voltage sweep across a makeshift Langmuir double probe, and derived equations to determine electron density and temperature from the resulting I-V trace. This work resulted in a first-author publication that was accepted to the 2024 International Electric Propulsion Conference, as well as a poster presentation.

In 2023, my interest in accelerators and particle dynamics brought me to an REU at the University of Minnesota with Dr. Jeremiah Mans of the High Energy Physics Group, where I worked closely with a graduate student and utilized machine learning techniques to analyze data from the Large Hadron Collider in search of dark matter. Following High-Luminosity upgrades to the Compact Muon Solenoid detector, I modified our existing code framework to integrate data from sections of the detector with enhanced resolution. My work involved generating and analyzing Monte Carlo simulations using C++ and Python, training a boosted decision tree algorithm to identify dark matter events in simulation, then evaluating its performance and comparing it to modified versions of the algorithm. I found a systematic field miscalculation in the lab's track projection code by manually calculating muon trajectories in through a spatially-varying magnetic field in polar coordinates, and after plotting relative efficiencies in different regions of the detector, I even discovered dead cells in some of the drift tube layers that had to be removed from the study. I concluded my REU with a poster and oral presentation, learning many important coding, simulation, and data analysis skills that may be integral for future research.

My current work involves simulating thermosphere environments. Specifically, I am working on a contract to determine the erosion yields of neutral atomic oxygen (AO) on various ceramic samples. This work has involved setting up cryopumps and maintaining an AO source. Diagnostics include a Faraday probe, retarding potential analyzer, Wien filter, and a carbon-coated quartz crystal microbalance (QCM). I am currently working on literature reviews and coordinating with multiple undergraduate students to achieve goals in different aspects of the project, like implementing the QCM or dismantling and servicing the AO source.

After finishing my PhD, my dream is to one day work at JPL studying advanced propulsion concepts and developing mission-ready thrusters. The NASA Space Technology Graduate Research Opportunity Fellowship would allow me to pursue my thruster research in a capacity that I do not currently have without dedicated funding for a propulsion project. The chance to directly collaborate with NASA experts and contribute to advancements in propulsion technologies for small satellite and deep-space applications would be monumental to me. I believe that my project can be instrumental in supporting NASA's objectives for cost-effective, efficient, and extended missions.

Project Narrative: Novel Adaptations to a Helical-Electrode IEC Thruster

1. Introduction

Exploration of the outer planets is constrained by propulsion technologies that limit mission longevity, payload capacity, and precise maneuverability. Electric propulsion systems offer significant advantages in fuel efficiency and precision attitude control for long-duration missions. Our helical-electrode Inertial Electrostatic Confinement (IEC) thruster is a low-mass solution capable of operating on various gases and delivering an adaptable thrust range, while remaining simple to fabricate with minimal resources. Though traditional IEC devices are not utilized in practical applications due to limited thrust efficiency and scalability, this work explores novel physical effects unique to our thruster geometry that have the potential to rectify these issues, making it a competitive method for deep-space and small satellite applications where payload capacity is limited. The modifications we propose closely align with NASA's Transformational Capability R&D under T4: Fusion/AEP Concepts [1] and Technology Taxonomy TX01.4.4: Other Advanced Propulsion Systems [2], adapting fusion techniques to explore an early-stage propulsion concept with emerging possibilities.

2. Background

An IEC plasma is generated in low-pressure gases when high voltage is applied across a concentric electrode geometry consisting of an inner cathode and an outer anode. The electric field is strong enough to ionize the gas by stripping electrons from nuclei, leading to a steady plasma discharge. IEC devices were originally developed to study nuclear fusion [3] by accelerating positive hydrogen nuclei radially inward toward the lower potential well within the cathode, allowing them to collide and fuse. However, this interaction results in the buildup of a positive local space charge that eventually neutralizes regions in the cathode with the weakest electric fields, allowing charged particles to jet out [3]. While this beam is an issue for fusion devices, IEC thrusters leverage the effect to generate thrust.

3. Current Work

To investigate this phenomenon, we first built a proof-of-concept IEC device and achieved fusion from a remote-operated LabVIEW interface at a 28 kV potential, 2–10 mA current, and at 10–15 mTorr pressure. Experimental success was confirmed by an isotropic neutron flux of 3.5×10^4 neutrons/s, which was detected via both a bubble dosimeter and REM detector. We then modified the setup to incorporate a compact IEC thruster, which utilizes a concentric helical electrode geometry to accelerate positive ions toward a central line. It is hypothesized that positive charges accumulate within the center of the inner cathode, acting as a secondary electrode [4]. The resulting discharge between the inner cathode and the virtual anode along the center line induces a flux of electrons toward the center, partially neutralizing the space and allowing a beam of plasma to escape through the outlet of the device, thereby generating thrust.

Figure 1: IEC Thruster Firing

3.1 Thruster Structure and Diagnostic Methods

Our device consists of two tungsten wire electrodes enclosed within a quartz tube, which is enclosed by ceramic endcaps that support an internal gas feedthrough. The setup operates within a pressure range of 50–150 mTorr at voltages ranging from 1–5 kV, producing plasma that exits through a small outlet in the endcap. Current diagnostic methods used to characterize the thruster include:

- **Magnetic Field Analysis**: An external magnetic field is applied perpendicular to the electron beam, and the resulting beam curvature at 4.5 kV confirms a composition of high-velocity electrons, with a measured velocity of up to 28,000 km/s, or approximately 10% the speed of light [5]. This is consistent with the theoretical range needed for electron-driven thrust, with velocities above 70% the ideal velocity for an electron accelerated directly across a 4.5 kV potential. A similar helical electrode experiment by the University of Kentucky involving higher mass flow rates found up to 100% of the ideal velocity at 2.2 kV and 3 kV [4].

- **Paschen Curves**: Minimum breakdown voltage occurs at 300 mTorr, but the ideal operating pressure range for plasma stability was found between 60–100 mTorr [5].

- **I–V Characteristics**: Current (I) increases with voltage (V), as expected, though we find distinct operating modes at different pressures. When plasma intensity is greater inside the thruster than in the exhaust beam, the system pulls much less current, indicating worse efficiency [5]. Our experiments have demonstrated that this is likely due to lower mass flow rates, even at consistent pressures. An improved response was observed at higher pressures when discharge modes transitioned from a collimated beam into a spray from the nozzle, though we expect that the greater exhaust divergence could have negative effects on thrust.

- **Langmuir Double Probe**: Electron temperature and density were calculated using an I-V trace analysis. Our makeshift probe measured current at various applied voltages, generating data that helped derive electron density (approximately 3.3×10^{9} cm^{-3}) and temperature (~95,000 K) [5].

Our diagnostics confirm that, despite setup limitations, the thruster emits a beam composed of high-velocity electrons with the potential to produce thrust on the order of millinewtons. Nevertheless, challenges within the current experimental setup present a need for optimization to fully validate the IEC thruster as a viable propulsion method.

4. Challenges and Initial Proposed Adaptations

The current iteration of our thruster faces several challenges, including:

- **Low Mass-Flow Rates**: Our flow rates are limited by the range of our mass-flow controller. Higher flow rates have been shown to achieve discharge currents and thrust that are an order of magnitude higher than our current setup [4].

- **Non-Ideal Vacuum Conditions**: Operating pressures in our system do not drop low enough to simulate real space environments at higher mass flow rates, and varying pressures affect beam formation and stability.

- **Insufficient Electrode Precision and Uniformity**: Our tungsten electrodes are hand-wound, leading to variability in the electric field. We recently 3D printed a pair of novel stainless-steel electrodes and expect that the higher structural precision will enable a more uniform field distribution and enhance confinement along the center axis [4].

- **Limited Beam Characterization and Assumptions of Quasi-Neutrality:** Our Langmuir double probe diagnostics assume a quasi-neutral beam emitted from the outlet, composed of high-velocity electrons and slow-moving ions. However, observations of the beam itself appear to show a discrete jump in divergence approximately 1 cm from the outlet, with the precise distance corresponding linearly to voltage applied to the thruster. This may indicate that slow-moving ions cloud around the outlet of the thruster or are ejected at a high angle of incidence with respect to the beamline, which would imply that our assumption of quasi-neutrality in the beam may not hold. Additional characterization techniques involving a Faraday probe (for current density), a retarding potential analyzer (for energy distribution), and a Wien filter (for particle species selection) could provide precise measurements of electron and ion velocities [6], improving our understanding of beam composition by drastically limiting the quantity of assumptions we must make.
- **Lack of Dedicated Thrust Stand:** Our setup lacks a thrust stand equipped to measure mN-range of thrust generated by the IEC device, limiting our ability to directly quantify thrust, thrust-to-power ratio, and specific impulse. We plan to utilize NASA resources (e.g., test facilities) or build a custom stand for precise, low-thrust measurements in a vacuum environment, which would provide critical data for optimizing performance.

Addressing these challenges could significantly enhance the performance and reliability of the IEC thruster, allowing us to develop an advanced framework of diagnostic tools, while also providing critical data on beam behavior that will guide the direction of our proposed research efforts:

4.1 Proposed Research Efforts

Proposed research will focus on studying physical phenomena unique to the geometry of our system with the potential to make IEC configurations viable for practical space applications.

One area of focus involves determining whether an IEC thruster can reduce fuel losses and achieve scalable thrust efficiencies by using a quadrupole magnet arrangement to precisely lens the beam through a minimizable outlet size [4], ensuring that only maximally accelerated plasma leaves the thruster. If the beam is dominated by electrons, maximal preservation of gas fuel could allow for extremely high specific impulses. Though a positive charge buildup in the body of the thruster would generally cause backflow, recent studies show that extraction of free electrons from magnetosphere environments using biased collectors may have the potential to neutralize the thruster [11]. We plan to study the viability of this effect in our thruster geometry via current density measurements and magnetosphere environment simulations. Different electrode / quadrupole arrangements could be rapidly prototyped by drilling various outlet sizes in glass slides, iteratively simulating field configurations in COMSOL Multiphysics, and 3D printing electrodes to observe which setup produces optimal beam collimation at maximal thrust efficiencies.

Should the electron beam be confirmed as quasi-neutral, with roughly equal numbers of high-velocity electrons and slow-moving ions, increased voltages should accelerate the electrons to relativistic velocities following the curve in Figure 2. According to Maxwell's equations, this will generate a magnetic field which radially confines the ions, resulting in a magnetically self-focusing configuration [8] with the potential to reduce beam divergence and even enhance thrust efficiency by catalyzing deuterium fusion, which initiates at potentials exceeding ~25 kV. This effect would not be subject to kink instabilities or neutralization inefficiencies [9]. Figure 2 shows observed data points from our own experiments and from a similar setup at the University of Kentucky [4], as well as the calculated ideal velocities and Lorentz (gamma) factor at different applied voltages:

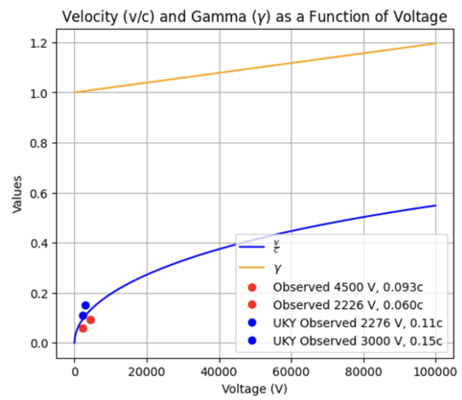

Figure 2: Electron Velocity and Lorentz Factor as Function of Voltage

Furthermore, observational data suggest that positive ions accumulate around the thruster outlet, creating a stagnant space charge that wastes the thrust potential of ions. An innovative solution may involve oscillating the electric field, similar to the Periodically Oscillating Plasma Sphere (POPS) techniques used by Los Alamos National Lab [10] to coordinate synchronized fusion collisions at a resonant frequency. By integrating a signal generator and high-voltage amplifier (and possibly also an electron injector for stabilization [10]), we aim to repurpose this effect in our linear geometry to achieve periodic ejection of ions as well as electrons, allowing the device to harness the thrust potential of both particles. The use of capacitors to accomplish this may also be explored, with the additional potential for achieving a true Z-pinch effect on top of the existing confinement geometry, all with a simple thruster design [7] [12].

5. Summary of Research Questions and Methods

- How can we validate current assumptions regarding quasi-neutral beam composition and electron density?
  - Approach: Use improved diagnostics, including a Faraday probe, retarding potential analyzer, and Wien filter to confirm electron and ion velocities, density, and beam quasi-neutrality. Combined with our initial adaptations to the setup, we expect to complete this within 6 months.
- What is the full range of optimal operating conditions (thrust, thrust efficiency, specific impulse) achievable by modified IEC configurations? Does lensing through an outlet increase thrust efficiency?
  - Approach: Rapidly prototype various outlet sizes, electrode geometries, and quadrupole magnet arrangements, then test their performance in different pressure and voltage ranges, optimizing for thrust, thrust efficiency, and specific impulse. If beam is dominated by electrons, determine if the density of free electrons in the magnetosphere is sufficient to neutralize charge buildup in our system. Initial testing should be completed by the 1.5-year mark.
- How does thrust scale with voltage as the thruster enters the fusion regime? Do relativistic electrons reduce beam divergence and enhance secondary fusion via magnetic confinement?
  - Approach: Simulate and test high-voltage configurations (up to 100 kV) to analyze relativistic effects on electron density, divergence, and thrust. We plan to begin rough proof-of-concept simulations at 1.5 years, with power supply integration and initial testing started by the 2-year mark, to be completed by 2.5 years.
- Can periodic oscillations increase thrust in IEC thruster electrode geometries by facilitating ion ejection and preventing the buildup of stagnant space charges?
  - Approach: Integrate a signal generator and high-voltage amplifier or a capacitor bank to induce an oscillating electric field, using periodic frequency adjustments and feedback

controls to assess impact on beam collimation and thrust. Experimental oscillation tests will follow the main testing and be completed within 4 years.

6. Relevance to NASA Technological Roadmap

The Inertial Electrostatic Confinement (IEC) electron thruster aligns with NASA's Transformational Capability R&D, specifically under *T4: Fusion/AEP (Advanced Energetic Propulsion) Concepts* [1]. This initiative focuses on early-stage R&D in nuclear fusion and advanced propulsion to achieve transformative capabilities for efficient solar system exploration. With its origins in fusion research, the novel IEC thruster generates thrust via directed electron emission, offering a compact, high-efficiency solution for deep-space propulsion.

The thruster's design allows it to operate on a variety of ionizable gases, minimizing reliance on traditional propellants and enabling longer mission durations. As NASA pursues technologies to operate efficiently across extreme environments, the IEC thruster's adaptability makes it a strong candidate for advancing energetic propulsion technology. Success in this project could pave the way for highly efficient propulsion systems, pushing the limits of space exploration within and beyond the solar system.

7. Visiting Technologist Experience

The prospect of the visiting technologist experience is very exciting, as it would provide the unique opportunity to engage with experts in the fields of fusion and propulsion. I believe that direct access to feedback and advice from NASA would be extremely beneficial to my research, especially due to its highly experimental and cross-disciplinary nature. I am primarily interested in working with the Jet Propulsion Laboratory (JPL) and Glenn Research Center (GRC). JPL's expertise in plasma diagnostics and electric propulsion would help guide refinements in beam collimation and electron confinement, improving thruster performance through advanced diagnostics and simulation. Meanwhile, GRC's specialized vacuum testing facilities could be crucial for validating thrust measurements and optimizing our design for deep-space environments. Such collaboration with NASA's experts would not only enhance my technical skills and streamline thruster development but also help me identify its most promising features, revealing the research directions with the highest potential for impact.

8. Conclusion

In summary, our thruster concept offers a compact, versatile solution for deep-space missions requiring high fuel efficiency and low mass. This project's diagnostics and experiments will provide insights into beam collimation, quasi-neutrality, and relativistic effects, with the potential to dramatically enhance thrust, thrust efficiency, and specific impulse. Funding for our experiments would allow us to study physical phenomena unique to the geometry of our system and leverage them to develop more powerful and efficient thrusters with operating parameters that fit within the constraints of deep-space and small satellite applications. Overall, this work aligns closely with NASA's goal of advancing low-TRL propulsion technology for deep-space exploration, aiming to elevate the IEC electron thruster concept from its current early experimental stages to TRL 3/4 [13].

References

[1] NASA Space Technology Mission Directorate. (2023). GO: Advanced Propulsion. NASA. https://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=1021228/solicitationId=%7B16279836-6D7A-7103-4558-EF452A79CE53%7D/viewSolicitationDocument=1/GO-Advanced_Propulsion-2023-08-17.pdf

[2] National Aeronautics and Space Administration. (n.d.). 2020 NASA technology taxonomy. NASA. https://www.nasa.gov/otps/2020-nasa-technology-taxonomy/

[3] Chan, Y.-A., & Herdrich, G. (2018). Jet extraction and characterization in an inertial electrostatic confinement device. Vacuum. doi:10.1016/j.vacuum.2018.07.053

[4] Winter, M., Koch, H., Green, R. W., & Hartsfield, C. R. (2019). Direct Inertial Electrostatic Confinement Propulsion at Low Power Levels. Presented at the 36th International Electric Propulsion Conference, University of Vienna, Vienna, Austria, September 15-20, 2019. IEPC-2019-xxx.

[5] Auerbach, J., Bilén, S. G., & Winter, M. (2024). Investigating Beam Divergence and Characteristics in a Helical Electrode Inertial Electrostatic Confinement Thruster. Presented at the 38th International Electric Propulsion Conference, Toulouse, France, June 23-28, 2024. IEPC-2024-781.

[6] Hall, S. J., Jorns, B. A., Gallimore, A. D., Kamhawi, H., & Huang, W. (2018). Plasma Plume Characterization of a 100 kW Nested Hall Thruster. *Journal of Propulsion and Power, 34*(6), 1356-1365. https://doi.org/10.2514/1.B38081

[7] Delzanno, G. L., Borovsky, J. E., Thomsen, M. F., & Moulton, J. D. (2015). Future beam experiments in the magnetosphere with plasma contactors: The electron collection and ion emission routes. Journal of Geophysical Research: Space Physics, 120(5), 3588–3602. doi:10.1002/2014ja020683

[8] Budker, G. J. Relativistic Stabilized Electron Beam. CERN Document Server, Record No. 1241561., https://cds.cern.ch/record/1241561/files/p68.pdf

[9] Bennett, W. H. (1955). Self-focusing streams. Physical Review, 98(6), Naval Research Laboratory, Washington, D.C. Received September 30, 1953; revised November 10, 1954.

[10] Park, J., Nebel, R. A., Stange, S., & Murali, S. K. (2005). Periodically Oscillating Plasma Sphere. Physics of Plasmas, 12(5), 056315. https://doi.org/10.1063/1.1888822. Published by the American Institute of Physics.

[11] Shumlak, U. (2020). Z-pinch fusion. Journal of Applied Physics, 127(20), 200901. https://doi.org/10.1063/5.0004228

[12] Levitt, B., Meier, E. T., Umstattd, R., Barhydt, J. R., Datta, I. A. M., Liekhus-Schmaltz, C., Sutherland, D. A., & Nelson, B. A. (2023). The Zap Energy approach to commercial fusion. Physics of Plasmas, 30(9), 090603. https://doi.org/10.1063/5.0163361

[13] Manning, C. G. (2023). Technology readiness levels. National Aeronautics and Space Administration. https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/

[14] Winter, M., & Koch, H. (2017). Inertial Electrostatic Confinement Plasma Devices – Potential Thruster Technology for Very Accurate Attitude Control Systems. Presented at the 35th International Electric Propulsion Conference, Georgia Institute of Technology, Atlanta, Georgia, USA, October 8–12, 2017. IEPC-2017-549.

[15] Schmidt, G., Jacobson, D., Patterson, M., Ganapathi, G., Brophy, J., & Hofer, R. (2018). Electric Propulsion Research and Development at NASA. NASA Glenn Research Center. Presented at the International Astronautical Congress, Bremen, Germany. Document ID: 20180007179.

[16] Leach, R., & Neal, K. L. Discussion of Micro-Newton Thruster Requirements for a Drag-Free Control System. 16th Annual/USU Conference on Small Satellites, SSC02-VIII-1. Design_Net Engineering, Lakewood, CO.

[17] Holste, K., Dietz, P., Scharmann, S., Keil, K., Henning, T., Zschätzsch, D., Reitemeyer, M., Nauschütt, B., Kiefer, F., Kunze, F., Zorn, J., Heiliger, C., Joshi, N., Probst, U., Thüringer, R., Volkmar, C., Packan, D., Peterschmitt, S., Brinkmann, K.-T., ... & Klar, P. J. (2020). Ion thrusters for electric propulsion: Scientific issues developing a niche technology into a game changer. Review of Scientific Instruments, 91(6), 061101. https://doi.org/10.1063/5.0010134

[18] Goebel, D. M., & Katz, I. (2008). Fundamentals of Electric Propulsion: Ion and Hall Thrusters. John Wiley & Sons.

NSTGRO Schedule

The following are classes I will have completed by the start of the program:
NUCE 497 – Plasma Lab | AERSP 508 – Fluid Mechanics | EMCH 524 – Mathematical Methods of Engineering | AERSP 590 – Colloquium | EDSGN 558 – Systems Design | AERSP 550 – Astrodynamics | AERSP 470 – Advanced Aerospace Structures | AERSP 600 – Thesis Research

Year 1: August 2025 – August 2026 | Take qualifying exam in October
Research Milestones:

- Upgrade system and validate beam assumptions with new diagnostics (6 months)
- If beam is dominated by electrons, determine if the density of free electrons in the magnetosphere is sufficient to neutralize charge buildup
- Develop prototyping scheme for different configurations and outlet sizes. Begin testing.

Coursework: EE 430 – Principles of Electromagnetic Fields | EE 531 – Engineering Electromagnetics | AERSP 590 – Colloquium | EE 432 – RF and Microwave Engineering | AERSP 540 – Theory of Plasma Waves | AERSP 600 – Thesis Research

Year 2: August 2026 – August 2027 | Beginning of PhD program
Research Milestones:

- Complete initial configuration tests to determine optimal parameters, using thrust, efficiency, and specific impulse as metrics (1.5 years)
- Characterize applicable mission phase-space (1.5 years)
- Complete simulations and set up system to study fusion and relativistic effects (2 years)

Coursework: AERSP 490 – Intro to Plasmas | AERSP 535 – Physics of Gases | AERSP 600 – Thesis Research

Year 3: August 2027 – August 2028
Research Milestones:

- Complete HV testing, and determine whether relativistic electrons and fusion effects enhance thrust by observing voltage scaling and comparing to simulation (2.5 years)
- Begin integration of a signal generator, high voltage amplifier, feedback controls, and possibly an electron injector to induce resonant frequency oscillating electric field

Coursework: AERSP 600 – Thesis Research

Year 4: August 2028 – August 2029
Research Milestones:

- Complete integration and achieve resonant frequency effects, as monitored by feedback controls (3.5 years)
- Observe visual beam dynamics and determine impact on thrust / thrust efficiency by taking measurements at different frequencies and offset biases (4 years)
- Characterize how novel physics phenomena affect performance and shift the applicable mission phase space (4 years)

Coursework: AERSP 600 – Thesis Research