EPC-RFT-1 Expedient Radio Frequency Gridded Ion Thrusters

Claude Blue[1], Griffin Minter[2]
University of Alabama in Huntsville, Huntsville, Alabama, 35899, United States of America

Themistoklis Chronis[3]
University of Alabama in Huntsville, Huntsville, Alabama, 35899, United States of America

This paper reports on the design, development, and fabrication of the EPC-RFT-1 system, an Expedient Radio Frequency Gridded Ion Thruster (RF-GIT) developed for instructional and laboratory use by the University of Alabama in Huntsville Electric Propulsion Club, with emphasis on its design philosophy, preliminary progress, and future goals.

Nomenclature

DC	=	Direct Current
GIT	=	Gridded Ion Thruster
HVPS	=	High Voltage Power Supply
Isp	=	Specific Impulse
PMD	=	Propellant Management System
PPU	=	Power Processing Unit
RF	=	Radio Frequency
RFT	=	Radio Frequency Thruster
sccm	=	Standard Cubic Centimetres per Minute (unit of volume flow rate)
V	=	Volts (unit of electrical potential)
$\dot{V}$	=	Volume Flow Rate
VScreen	=	Screen Grid Voltage
VAccel	=	Accelerator Grid Voltage

I. Introduction

[1]Chancellor & Research Lead, UAH Electric Propulsion Club, AIAA Undergraduate Student Member

[2]STARGATE Project Permanent Team Member, AIAA Undergraduate Student Member

[3]Principal Investigator, Electric Propulsion Club, University of Alabama in Huntsville

The EPC-RFT-1 system is developed by the Electric Propulsion Club, an Independent Student Research Group at the University of Alabama in Huntsville. The purpose of the work is the realisation of a device capable of essential functional elements of an RF-GIT device as widely utilised for spaceflight, while being low-cost, readily reproducible, and modular for future iterations. The device is currently under construction and testing. Once the device is able to prove reliable and successful operation and successful fulfilment of all project requirements, the entirety of the design, documentation, and fabrication guide will be published in a book titled Expedient Radio Frequency Gridded Ion Thrusters, along with its companion website, and will be made open source.

II. Project Introduction and Background

Gridded Ion Thrusters (GITs) are a class of electric propulsion systems that employ electrostatic ion extraction and acceleration through biased grid assemblies. A defining characteristic of GIT architectures is the physical and functional separation of plasma production from ion extraction, a feature preserved across multiple variants.[1] Plasma generation may be achieved through several mechanisms, including electron-emitting hollow cathodes, induction-coupled radio frequency (RF) ionisation, and microwave-driven discharges.[2]

With the rapid commercial industrialisation of Earth orbit in the "New Space" era, demand has increased for low-cost, high-specific impulse (Isp), and mass-producible electric propulsion systems. Among low-power architectures, Radio Frequency Gridded Ion Thrusters (RF-GITs) represent one of the most efficient and mature technologies currently available. Despite the successful deployment of multiple heritage TRL 9 flight systems, including the RIT series developed by ArianeGroup and the ThrustMe NPT-30-I2, RF-GIT technology remains comparatively underutilised relative to Stationary Plasma Thrusters (SPTs) and other Hall Effect Thruster (HET) variants. This disparity arises in part from limited institutional accessibility, reduced exposure within academic programmes, and comparatively modest commercial incentives for broader development and innovation.

The EPC-RFT-1 is conceived as a complete RF gridded ion thruster system capable of demonstrating the essential functional elements of an RF-GIT system and fulfilling all defined project requirements, including sustained and stable RF plasma generation, ion extraction and acceleration, and plume neutralisation. In contrast to flight-optimised systems, the present design prioritises rapid fabrication, low cost, and modular interchangeability of components. The system is intended to support extended continuous test-firing, enabling plasma diagnostic studies and investigation of erosion mechanisms. The current configuration has an estimated material cost of approximately $4,700, inclusive of the thruster assembly, neutraliser, power processing unit, and propellant management system, with an estimated total fabrication time of approximately 19 hours.

III. Project Requirements & Material Selection

A. High-Level System Requirements

The EPC-RFT-1 system has been developed to realise, in laboratory form, the essential functional elements of a gas-fed Radio Frequency Gridded Ion Thruster (RF-GIT). The overall architecture is informed by published descriptions of the Arianespace RIT-3.5, where available in the open literature from the Electric Rocket Propulsion Society (ERPS). The present device is intended to serve as an instructional and experimental analogue of a generic RF-GIT system, rather than a direct replication of the RIT-3.5.

The EPC-RFT-1 system is designed for instructional and laboratory use and is not intended for flight qualification. Consequently, absolute performance metrics such as thrust, specific impulse, and efficiency are not primary design drivers. Instead, emphasis is placed on reliable ignition, repeatable operation, and clear manifestation of RF-GIT physical behaviour. This represents a deliberate trade-off: peak propulsion performance is moderated in favour of robustness, interpretability, and suitability for teaching and controlled experimentation.

The discharge chamber must reliably ignite when the prescribed start-up sequence is followed. Stable operation is required at propellant flow rates below 2.5 sccm, a constraint imposed by the pumping capacity of the testing environment, as later described in Section V. Under steady conditions, the discharge should produce a visible and spatially uniform glow. While optical observation is not a quantitative plasma diagnostic, a stable luminous discharge provides an immediate qualitative indication of sustained ionisation and acceptable discharge stability, particularly in instructional settings.

The ion extraction system employs independently biased screen and accelerator grids to extract ions from the plasma sheath and accelerate them to high exhaust velocities. The downstream beam current must remain stable with low temporal fluctuation under steady-state conditions. Variations in applied potential between V_Screen and V_Accel should produce predictable and physically consistent changes in beam current and beam profile, consistent with space-charge-limited flow behaviour. The objective is not to maximise beam current, but to demonstrate clearly the relationship between plasma density, grid voltage, and extraction behaviour. This reflects a trade-off favouring controlled and interpretable performance over maximum output.

The neutraliser must provide sufficient electron emission to maintain plume quasi-neutrality and prevent ion backstreaming or charge accumulation on the chamber walls or thruster structure. To simplify the system and eliminate the need for a secondary propellant feed line, a “dry” neutraliser using thermionic emission from a resistively heated element is selected for the EPC-RFT-1 system. This approach reduces plumbing complexity, lowers cost, and enhances suitability for laboratory use, while accepting practical limitations in emission margin and filament lifetime.

The system is intended to support long-duration test firing and plasma diagnostic experimentation. It is also designed to exhibit measurable erosion and degradation within practical laboratory timescales, including visible and predictable degradation in performance modes associated with common failure mechanisms. The target cumulative operational lifetime is 1500 hours. By the end of this period, observable effects should include pitting and grooving of the ion optics, aperture enlargement due to sputter erosion, deposition of grid material within the discharge chamber, and evidence of thermal stress in the grid assembly. Unlike flight thrusters, where erosion minimisation is critical, this system intentionally permits measurable wear in order to facilitate the study of lifetime-limiting mechanisms.

Operational simplicity is a key requirement. The thruster is supplied through a single regulated propellant line and powered by a bench-top Power Processing Unit (PPU) with clearly defined controls and interlocks. The start-up sequence is designed to be unambiguous and repeatable, enabling operation by users with limited prior experience in gridded ion propulsion. While this reduces operational flexibility and fine optimisation capability, it significantly lowers the risk of operator error and improves suitability for instructional environments.

Finally, the system must be designed to be cost-conscious in both material selection and fabrication. It shall be composed of commonly available materials that fulfil the requirements outlined in Section B. These materials must be capable of being fabricated and processed to acceptable tolerances using commonly available workshop equipment, such as conventional lathes and enclosed CNC milling machines, or by utilising Commercial Off-The-Shelf (COTS) components where appropriate. The entire thruster assembly must remain within the practical manufacturing capacity of a team of trained and informed undergraduate or graduate students or by dedicated hobbyists, operating within facilities typically available in university machine shops and chemistry laboratories. This requirement represents a deliberate trade-off favouring accessibility and reproducibility over specialised materials or advanced manufacturing methods.

B. Material Selection

At the prototype level, material selection was governed primarily by vacuum compatibility and anticipated thermal loading within the discharge environment. All materials intended for installation inside the vacuum chamber comply with ASTM E595 outgassing criteria to minimise contamination during extended operation. Components directly exposed to the plasma are specified for sustained operation at temperatures exceeding 500 °C, reflecting expected ion bombardment heating and radiative loading. Non-plasma-facing internal components are specified for operation up to approximately 250 °C, consistent with conductive and radiative heat transfer within the thruster assembly.

The thruster shell is fabricated from 6061 aluminium alloy, selected for its low cost, ease of manufacture, and widespread availability as a standard engineering material. It is used for all structural components of the thruster head that are not part of the ion optics assembly and do not require electrical insulation.

The discharge chamber consists of a commercially available (COTS) alumina ceramic tube of greater than 98% purity. The downstream end is terminated by an end plug machined from a glass-ceramic dielectric marketed under the trade name MACOR. Ceramic materials are employed for the discharge chamber in order to provide electrical isolation and withstand elevated temperatures associated with sustained plasma operation.

The discharge tube is mechanically clamped to the endcap using ceramic fasteners. Sealing is achieved externally using a low-outgassing epoxy (Torr Seal), applied only to non-plasma-facing surfaces in order to avoid direct exposure to the discharge environment.

The RF antenna is formed from an 8 AWG solid soft copper conductor, wound into a six-turn coil. The coil is supported by a dielectric guide. Owing to the geometric complexity of the guide, which renders subtractive manufacture impractical, it is currently produced by additive manufacturing using Z-PEEK, a low-outgassing, high-temperature thermoplastic suitable for vacuum environments.

The ion optics are manufactured from 304 stainless steel, selected on the basis of cost, availability, mechanical hardness, relative ease of machining and compatibility with post-machining surface treatment.

IV. Design Overview

A. General Overview

The EPC-RFT-1-A device is the current reviewed and approved baseline design of the EPC-RFT-1 system, and is currently being fabricated. The system follows a modular architecture in which the discharge chamber, ion optics assembly, neutraliser, power processing unit, and propellant management system are mechanically distinct yet functionally integrated.

The thruster head consists of a dielectric discharge chamber enclosed within an aluminium structural shell. Downstream of the discharge region, a three-grid ion optics assembly provides ion extraction and acceleration. A thermionic neutraliser is mounted at the exhaust plane to ensure plume charge neutrality during operation. Electrical power is supplied via a bench-top Power Processing Unit, and propellant is delivered through a single regulated feed line controlled by a mass flow controller.

The configuration emphasises mechanical robustness, repeatable alignment, and ease of assembly, while maintaining compatibility with the test facility described in Section V. Subassemblies are designed to allow inspection and replacement of key components, particularly the ion optics and neutraliser, in support of iterative development and experimental modification. A rendering of the EPC-RFT-1-A baseline configuration with neutraliser is shown below in Figure 1.

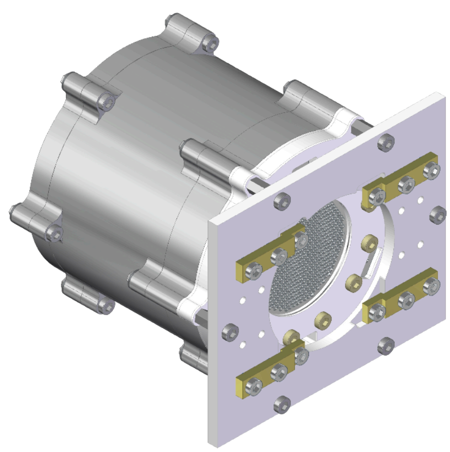

Figure 1 EPC-RFT-1-A Prototype With Neutraliser2

B. Ion Optics

The EPC-RFT-1 ion optics assembly employs a three-grid architecture fabricated from 304 stainless steel. The grids are machined on an enclosed CNC milling machine, with drill bit replacement scheduled after every 115 apertures to maintain dimensional consistency. A sacrificial aluminium backing plate is placed beneath the stainless steel stock, serving both as a fixture and as a breakout support to reduce exit-side burring and simplify post-processing without distorting the aperture geometry.

Following drilling, the grids are electropolished using an electrolyte solution consisting of 10% deionised water, 75% phosphoric acid (H_3PO_4), and 15% sulphuric acid (H_2SO_4). The grids are subsequently passivated in a 33.5% nitric acid (HNO_3) solution to remove residual contaminants and improve corrosion resistance.

The EPC-RFT-1 grids are hexagonal in planform and incorporate locking tabs on four of the six sides. Three tabs serve purely as geometric alignment features to prevent rotational misalignment, while the fourth functions additionally as a charging tab. The tabbed locking scheme, combined with the hexagonal grid profile seated within a matching hexagonal housing, ensures repeatable alignment of the grid stack. The assembly is secured using twelve alumina ceramic M4 fasteners.

The grid stack is housed within a MACOR enclosure that fully captures the outer rims of the grids. Inter-grid spacing is maintained using MACOR spacers CNC machined from 1 mm thick stock. This spacing was selected to favour mechanical robustness and ease of handling over optimised ion optics efficiency. While the spacer thickness is relatively large for this class of ion optics, it reflects practical fabrication constraints and the requirement for expedient construction within available resources.

Each grid contains 551 apertures arranged in a hexagonal array. The screen grid is 0.8 mm thick with aperture diameters of 2.1 mm. The accelerator and decelerator grids have aperture diameters of 1.6 mm and 2.0 mm, respectively.

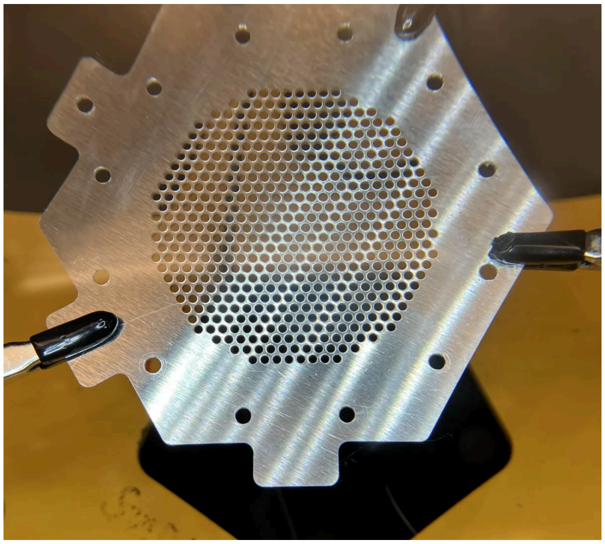

Figure 2 EPC-RFT-1-A Accel Grid (pre-electropolishing)

C. Neutraliser

The EPC-RFT-1 is designed to utilise a thermionic hot filament cathode neutraliser assembly, as shown in Figure 2 is inspired by the neutraliser as deployed on the Thrust-Me NPT30-I2 Iodine GIT.[7]

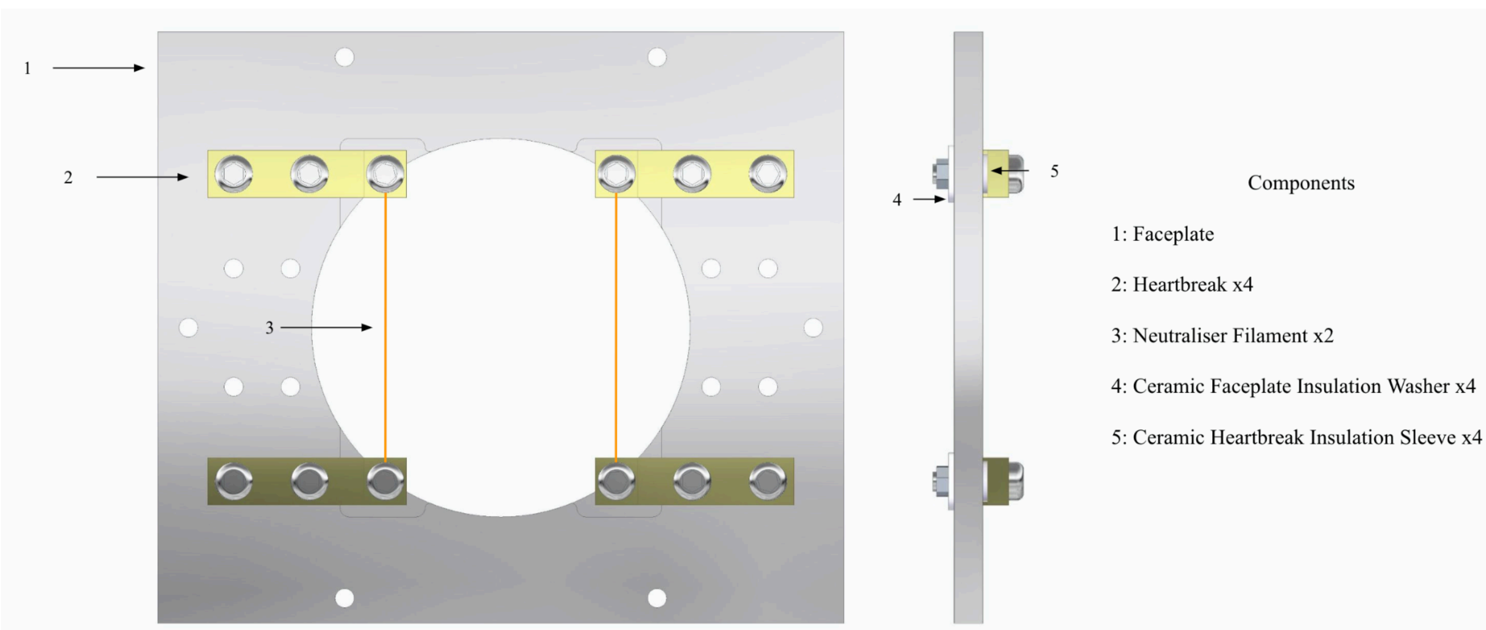

Figure 3. EPC-RFT-1 Neutraliser Assembly

This neutraliser assembly, informally referred to as the *"Lightbulb"* assembly, consists of two tungsten filaments mounted on either side of the neutraliser face plate. The filaments are supported by four brass heat breaks, which are secured to an aluminium mounting plate. Ceramic fittings are utilised at each interface to provide thermal insulation and to limit conductive heat transfer to the face plate.

When electrical current is applied to the tungsten wires, the filaments are heated to incandescence, causing thermionic emission of electrons, hence the designation *"lightbulb."* These emitted electrons are directed into the ion beam plume exiting the thruster, where they combine with the positive ions to neutralise the overall charge of the exhaust.

The *"Lightbulb"* design was selected for its simplicity in initial prototype testing. In contrast to hollow cathode neutralisers, it does not require a dedicated propellant feed or precise flow-matching with the main discharge plenum. While this approach is generally regarded as less than ideal for long-duration operation or adaptability, it is a sufficient system for early testing, and similar thermionic filament neutralisers have been successfully employed in flight systems. The neutraliser assembly is secured with six trimmed steel standoff nuts located at the edge of the thruster exhaust. By varying the length of the standoff nuts, the position of the filaments relative to the discharge plume can be adjusted.

V Testing Chamber Setup

The EPC-RFT system will be tested in the EPC's new High Vacuum Testing Chamber, which is currently under construction. This chamber is a small high-vacuum chamber, 9 ¾ in. internal diameter and 9 ⅜ in. tall. The chamber has four ports utilising ISO-K and ISO-KF flanges. It has 4 flanges consisting of K-100, K-63, KF-40, and KF-25. As shown in Figure 4 below, the chamber is configured to reflect the following. The chamber is pumped down using a Varian DS-102 roughing pump and a Pfeiffer TMH-071 turbo pump through the K-63 port. A K-63 to KF-40 to KF-63 tee connector will be connect the chamber to the turbopump and to attach a Granville Phillips 356002-YG-T vacuum gauge to the KF-40 flange on the T connector using a KF-40 to 2.75 in. CF connector.

The K-100 port serves as a viewport to visually identify the glow and take photos. The KF-40 port houses a 7-pin, 12 kV feedthrough flange used to supply power to the thruster, neutraliser, and receive data from instrumentation. The propellant management system of the EPC-RFT-1 system utilises an Omega Instruments 1–100 sccm electronic mass flow controller to supply argon gas to the thruster. Due to the lack of a hollow cathode and the use of a thermionic neutraliser, the system requires only one propellant feed line to the main plenum. The propellant management system employs a mix of AN-4 and ¼ in. NPT fittings. The feedline into the thruster is connected to the transit feedline and mass flow controller through a KF-25 gas feedthrough flange with Yor-Lok-style fittings.

The purpose of this chamber is to provide "proof of glow," ensuring the prototype can achieve sustained ignition and maintain stable plasma once ignited, as the propellant flow rate is reduced after the startup sequence. It also serves to confirm grid extraction capability via a rudimentary set of Faraday cups placed downstream of the thruster. Grid operation is confirmed if a higher beam current is observed when the gridded extraction system is on compared to off. This chamber is not large enough for accurate plume diagnostics or thrust quantification, nor is the TMH-071 turbopump capable of achieving the pumping speeds needed for continuous operation; such testing would be conducted in a dedicated diagnostic chamber. Here, its role is to validate the most fundamental capabilities and support troubleshooting prior to full-scale testing.

The chamber assembly is compact enough to be mounted on a 2-deck trolley, with the propellant feed lines and propellant management system built into the trolley itself and the gas bottle secured using a modified fire extinguisher wall fastener to one of the trolley legs. The PPU is also stowed on the platform on the bottom deck, as well as having extension cord spools where high voltage cross-country cables are stowed, which connect to instrumentation and the control panel. This configuration allows it to be used as an educational outreach demonstrator, where the thruster can be live-fired in front of an audience, anywhere power is available. It is also intended to solicit more funding and opportunities for test-firing the prototype in a larger-scale chamber and plasma diagnosis by demonstrating a repeatable demonstration of "proof of glow," and completion of the early phase of troubleshooting. The small size of the chamber ensures pump-down times within 25 minutes, and the startup sequence can be initiated in five minutes, during which time a presentation can be given.

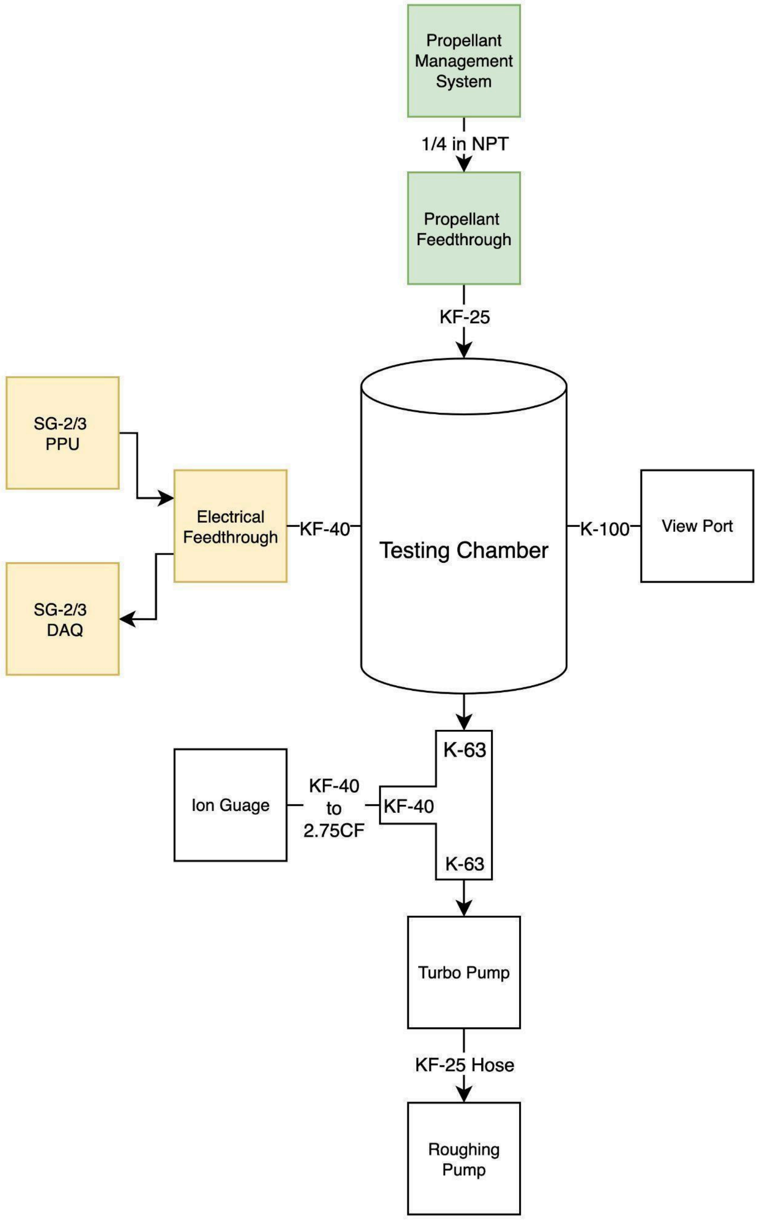

Figure 4. Testing Chamber Setup

VI Future Development Goals

The EPC-RFT-1 remains a work in progress, with the first fully integrated prototype expected to be completed in August 2026 and initial test-firing scheduled for September 2026. A second, smaller prototype designated EPC-RFT-2 is currently in the planning phase and is intended to address structural and integration issues identified in the present iteration. Development activities are being carefully documented to ensure traceability, reproducibility, and informed iteration in subsequent designs.

Thermal expansion and grid alignment represent persistent challenges in the current configuration. Plasma heating of the ion optics results in thermal expansion of the grids, which can introduce electric field distortion and, in severe cases, mechanical instability or loss of alignment. This is a well-documented issue in gridded ion thrusters and is further complicated by the use of dielectric grid supports in combination with conductive grid materials, resulting in differential thermal expansion. Several mitigation strategies have been examined, including alternative spacer geometries and modified clamping approaches; however, no fully satisfactory solution has yet been implemented.

VII. Conclusion

This paper has reported on the design, development, and fabrication of the EPC-RFT-1 system, an Expedient Radio Frequency Gridded Ion Thruster (RF-GIT) developed for instructional and laboratory use by the Electric Propulsion Club, an independent student research group at the University of Alabama in Huntsville. The objective of the project is the realisation of a device capable of demonstrating the essential functional elements of an RF-GIT system of the type widely utilised for spaceflight, while remaining low-cost, readily reproducible, and modular to support future iterations.

The EPC-RFT-1 is presently under construction and active development. As a prototype system, design modifications continue to be implemented during fabrication in response to practical constraints and emerging test data. Initial test-firing, with the objective of achieving a visible and stable glow discharge, is scheduled for September 2026. Subsequent testing, including beam current measurement and plume diagnostics, is planned for December 2026.

Upon successful validation of reliable operation and fulfilment of all project requirements, comprehensive documentation detailing design rationale, fabrication procedures, assembly methods, operational protocols, troubleshooting guidance, and performance data will be published in book form under the title Expedient Radio Frequency Gridded Ion Thrusters, accompanied by a companion website. The complete design package will be released as open-source material to the electric propulsion and electric rocketry communities, with the intention of encouraging replication, modification, and continued development as an accessible educational and experimental platform.

Acknowledgments

The STARGATE project team would like to offer our acknowledgement and sincerest gratitude to the Alabama Space Grant Consortium (ASGC), the University of Alabama in Huntsville College of Science Department of Physics and Astronomy, as well as the UAH Office of Technology Commercialization and the Office of the Vice President for Research and Development, for their continued support and funding of our ongoing research.

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