PHYSICAL OPTIMIZATION OF ION THRUSTERS IN A LOW EARTH ORBIT

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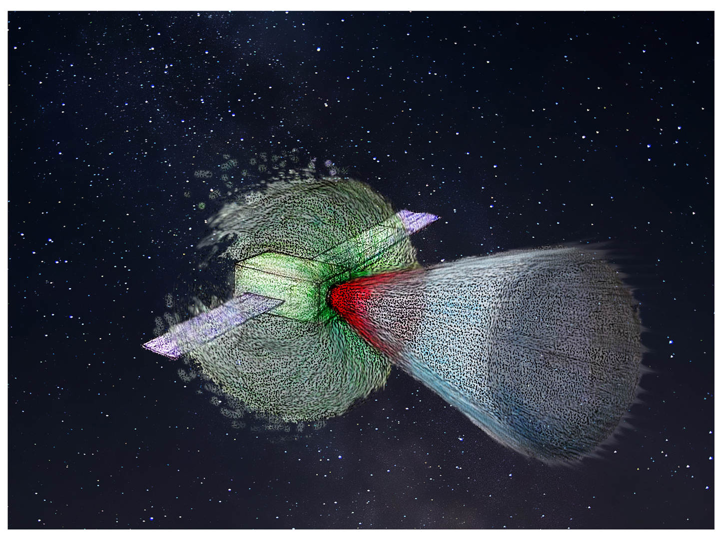
Introduction

The main technical and scientific development in the past years in the field of electric propulsion has been aimed at optimising efficiency [5]. Many recent electric propulsion systems are for small satellites [7] due to their increasing importance in creating mega constellations, such as the Iridium constellation [2] and the OneWeb project [5].

This research aims to modify and optimise the current design of what is considered to be a state of the art ion thruster, with a mixture of plasma physics, numerical modeling and general aerospace engineering approach in order to maximise performance, efficiency and lifetime.

Background

An ion thruster's plume is constructed of ions, neutrals and electrons [3]. These ions and neutrals arise from the ionised and non-ionised propellant particles, which are expelled from the thruster. The ionised propellant can be divided into two categories: fast moving ions and slow-moving ions. Fast-moving ions carry high energies imparted by the accelerator grids. Slow-moving ions are created by charged exchange collisions between the fast-moving ions and neutral particles which initially leave the thruster at thermal velocity [1]. Slow moving ions are produced in a region surrounding the thruster exit that will be henceforth be denoted as the charge exchange or CEX region. A diagram illustrating the different plume regions is shown below.



In the CEX region, there is backflow of slow-moving ions towards vulnerable parts of the satellite body that is caused by the electric field developing a radial component. These ions are more susceptible to electrostatic forces due to their lower velocity and therefore some displace backwards towards the satellite. Two forms of damage may be caused: sputtering (erosion and deformation) and deposition on the spacecraft surfaces. In the case of solar panels, external erosion is caused by the incoming particle flux [3].

A Magnetic Nozzle (MN) generates a convergent/divergent magnetic filed generated by either the use of permanent magnets or coils. This technology is now being researched in order to; increase propulsive performance, manage plume behaviour, and to apply it to Magnetically Enhanced Plasma Thrusters, which do not need the use of electrodes or a neutraliser.

Numerical Modelling Techniques

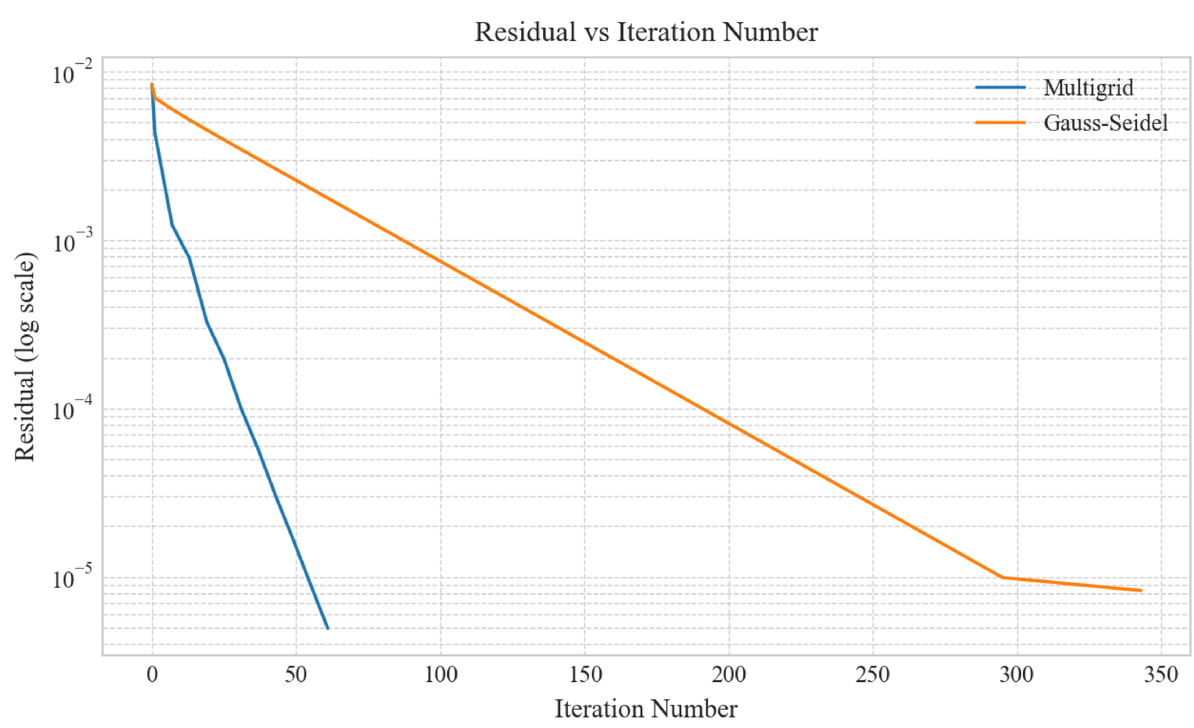
The electric and magnetic fields present in electric propulsion devices can be described by Maxwell's equations [3]. An in house Particle-In-Cell code is used to model the electric field using $\boldsymbol{E} = -\nabla\phi$. The particles' motions and acceleration are obtained from Lorentz force $F = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})$.

Particle to Particle collisions are handled by handled by Monte Carlo Collision (MCC) model as well as Direct Simulation Monte Carlo (DSMC). The particles which interact with a surface are modelled as a diffuse reflection [6]. The two main parameters are the coefficient of restitution and the coefficient of thermal accommodation.

	A	A+	Pr	Pr+
A	DSMC	MCC/DSMC	DSMC	MCC/DSMC
A+	—	DSMC	MCC/DSMC	DSMC
Pr	—	—	DSMC	MCC/DSMC
Pr+	—	—	—	DSMC

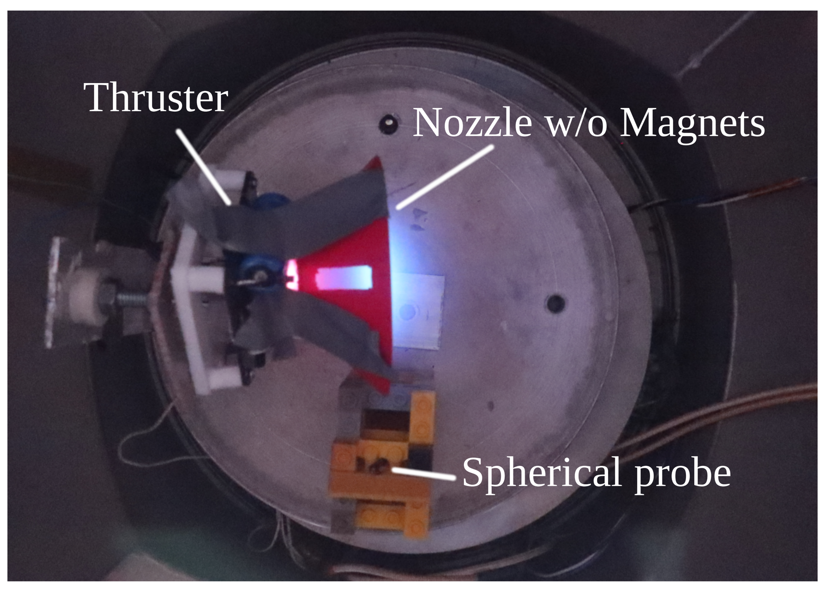
The mentioned in house code uses a novel method that minimises ease of access memory which is naturally parallelized whilst being able to deform the mesh. The spatial locality ratio is compared in the table below. Additionally a Multigrid scheme is developed to enhance the convergence of the grid generation method developed. The results of the Multigrid method can be seen in the figure below for a trampoline deflection problem.

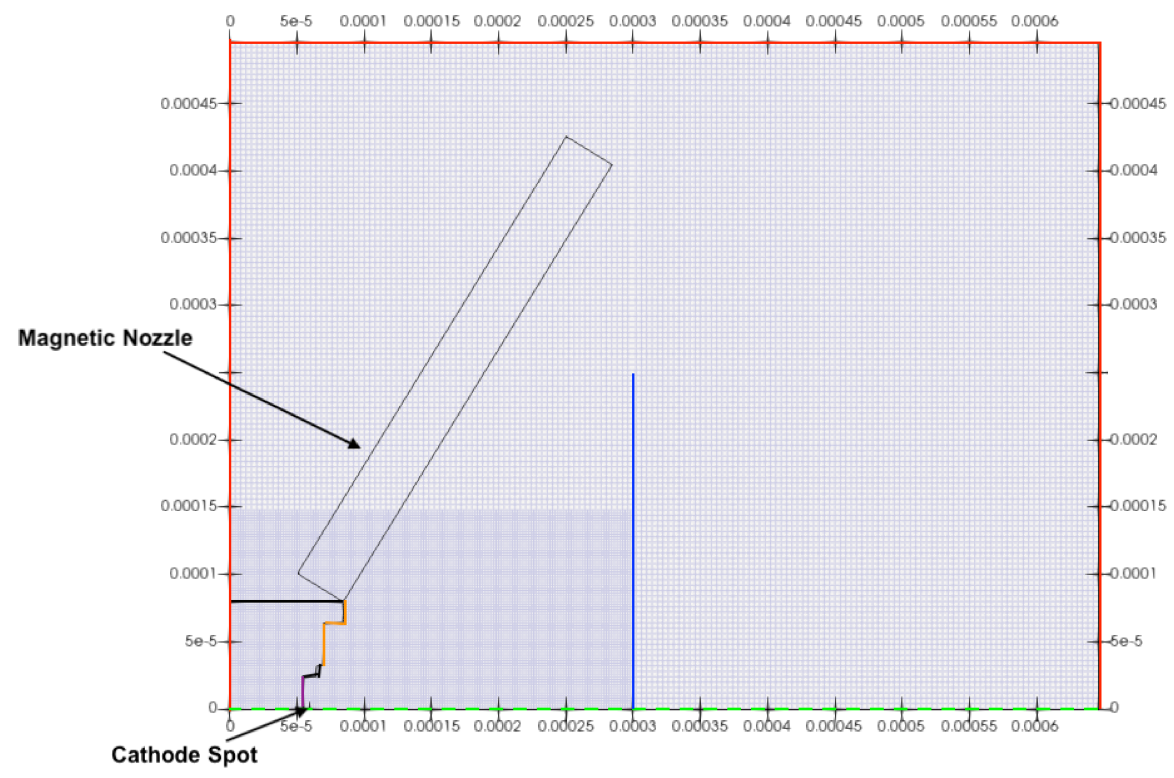
N of Cells	Cuthill-McKee	Z-order curve	Uniform Grid
100×100×100	0.38	0.62	0.20

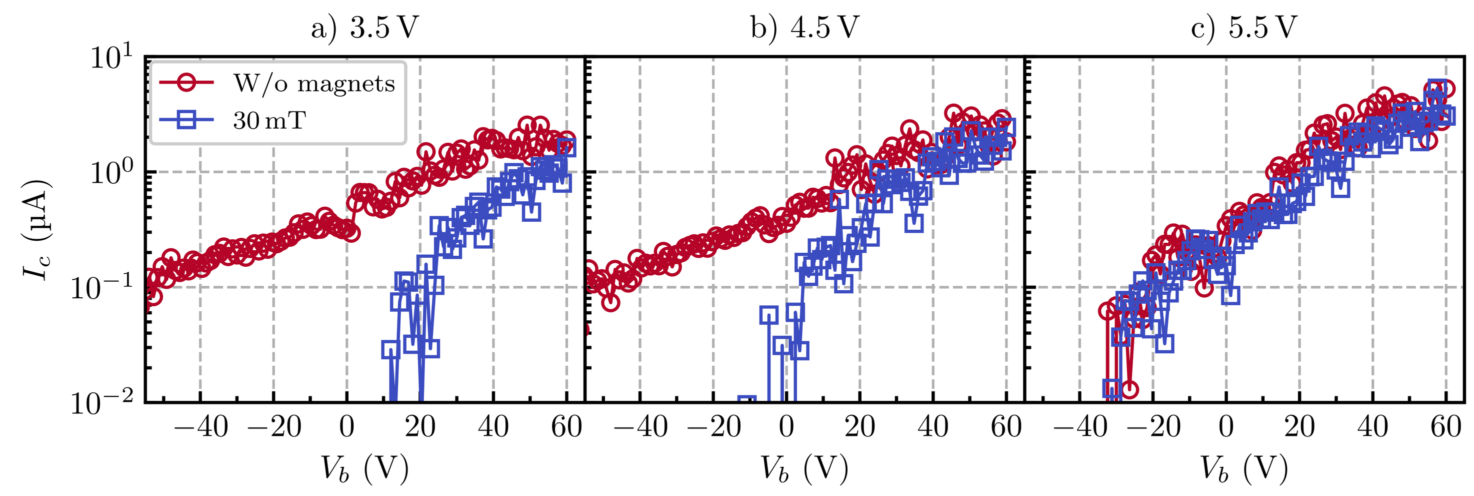


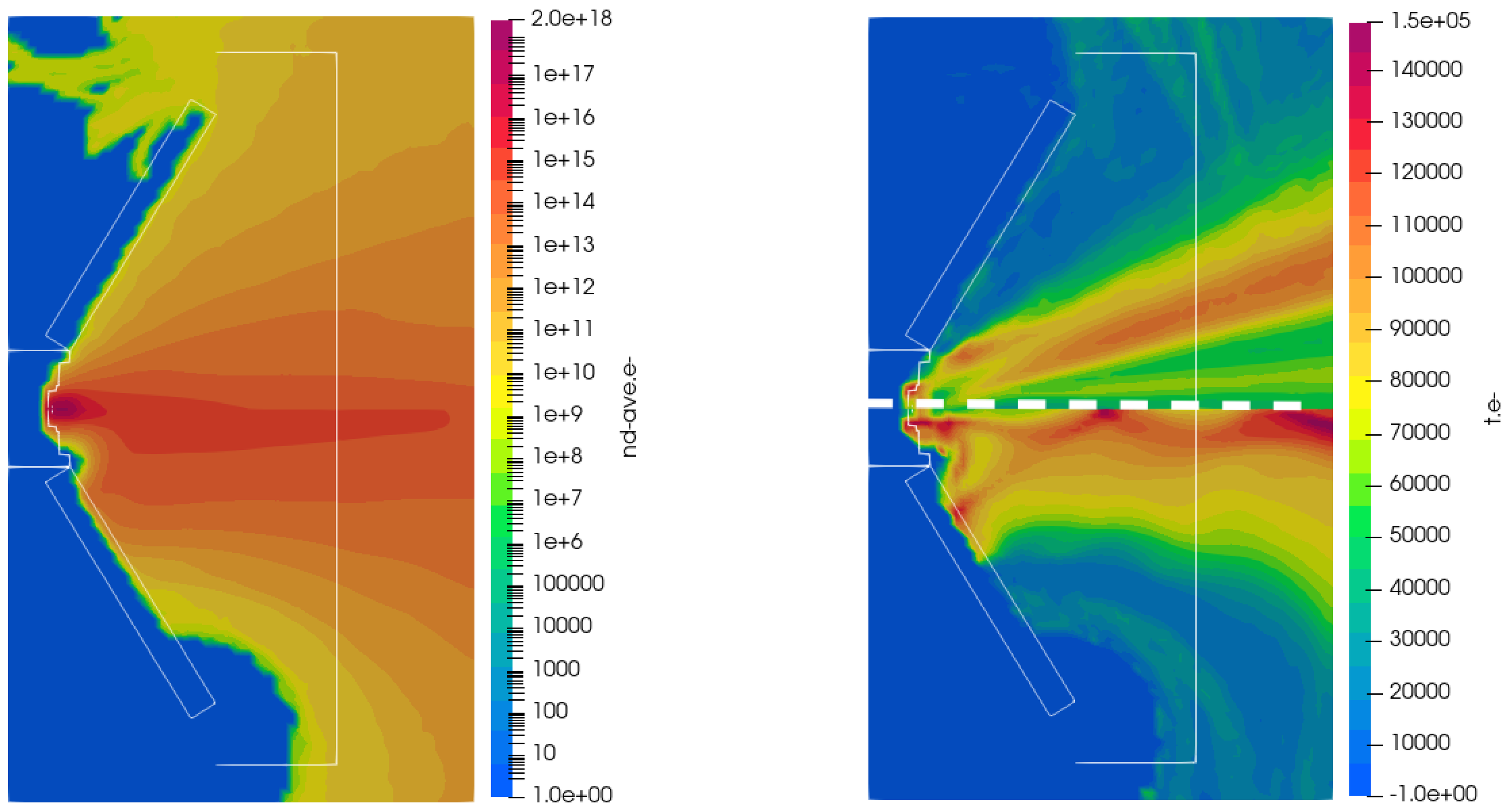
Magnetic Nozzle

Electron dynamics has been studied through a series of numerical simulations and laboratory experiments performed at the Technical University of Madrid. The results illustrated below representing the laboratory current-voltage and simulation electron number density and electron temperature have been formally presented at the 2025 IEPC conference in London [4]. The results reveal distinct patterns in electron confinement and backflow suppression, underscoring the influence of magnetic topology on detachment efficiency. Consistent findings from Langmuir probe diagnostics and PIC simulations indicate that a 30 mT magnetic nozzle effectively limits upstream electron transport and reshapes the plume, without increasing ion exhaust velocity. Overall performance gains are mainly attributed to higher discharge voltage, while the magnetic field primarily modifies electron confinement and plasma structure.









References

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