

Electron-Beam Generated ExB Plasma for Air-Breathing Propulsion

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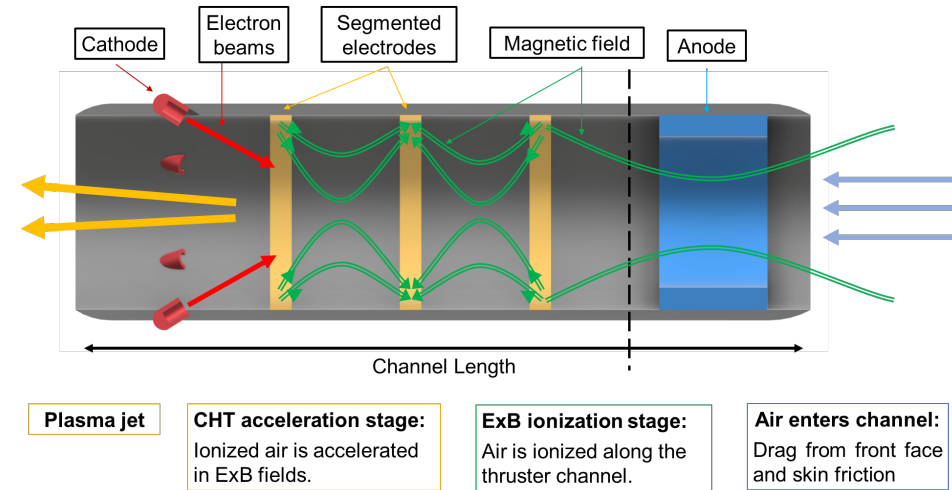
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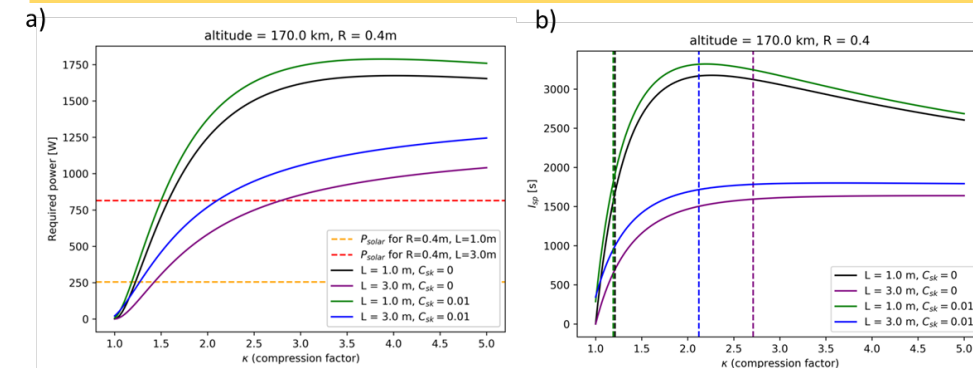
Goal of the Project

- Demonstrate the feasibility of a low power direct-flow airbreathing plasma thruster (AEBT) with two stages: air ionization by electron beams and ion acceleration by ExB fields (top figure).
- **Why is this important?**
- For a spacecraft to occupy a very low orbit (100-200 km), the on-board air-breathing propulsion (ABP) to compensate the air drag is an attractive propulsion option.
- Reduced inlet compression (direct flow) can enable the ABP thruster with feasible power and I_{sp} requirements (bottom figure).
- **What is the research approach?**
- Use of electron beams trapped in magnetic fields to efficiently generate the air breathing plasma at low pressures (10^{-3} - 10^{-6} torr) relevant to > 100 km.
- Lab experiments in 2 phases: 1st static air & 2nd with the inlet flow.
- Integrated experimental and modelling efforts applying time-resolved diagnostics and kinetic simulations supported by theory.

The proposed concept of the airbreathing electron-beam generated ExB plasma thruster



Effect of the compression factor on the required a) input power and b) I_{sp} to generate the thrust for drag compensation of a satellite with ABP



Assumptions: thruster efficiency of 0.25, 200 eV electron beam

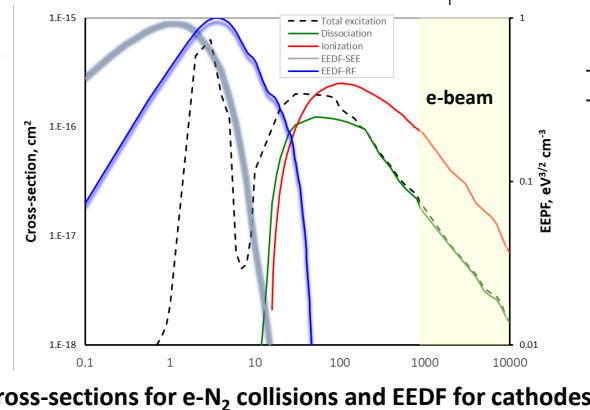
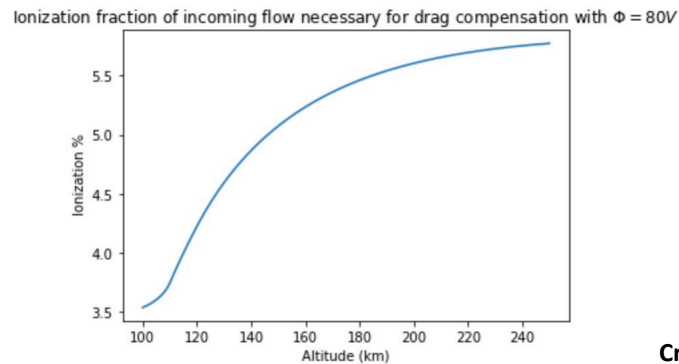


What was achieved in the research activity, and its impact?

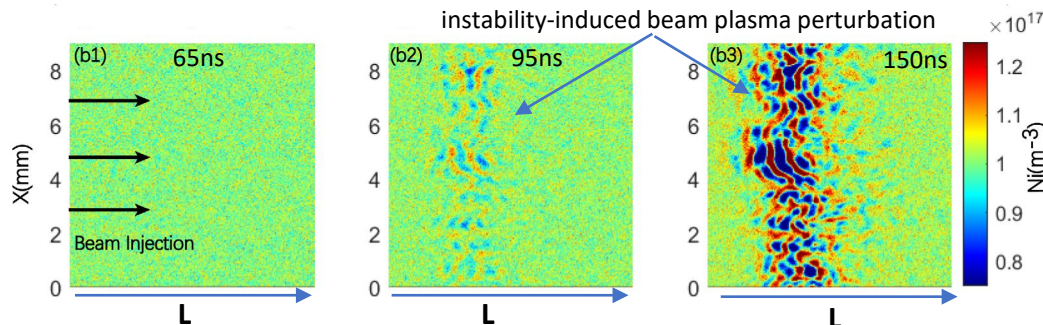
Modeling

- Conducted a theoretical assessment for the airbreathing thruster including a model of the drag and a global model for air ionization at relevant gas pressures (< 1 mtorr).

- Corroborated a key aspect of the project hypothesis: a low ionization of the flow (figure below) is sufficient to generate the thrust for drag compensation:

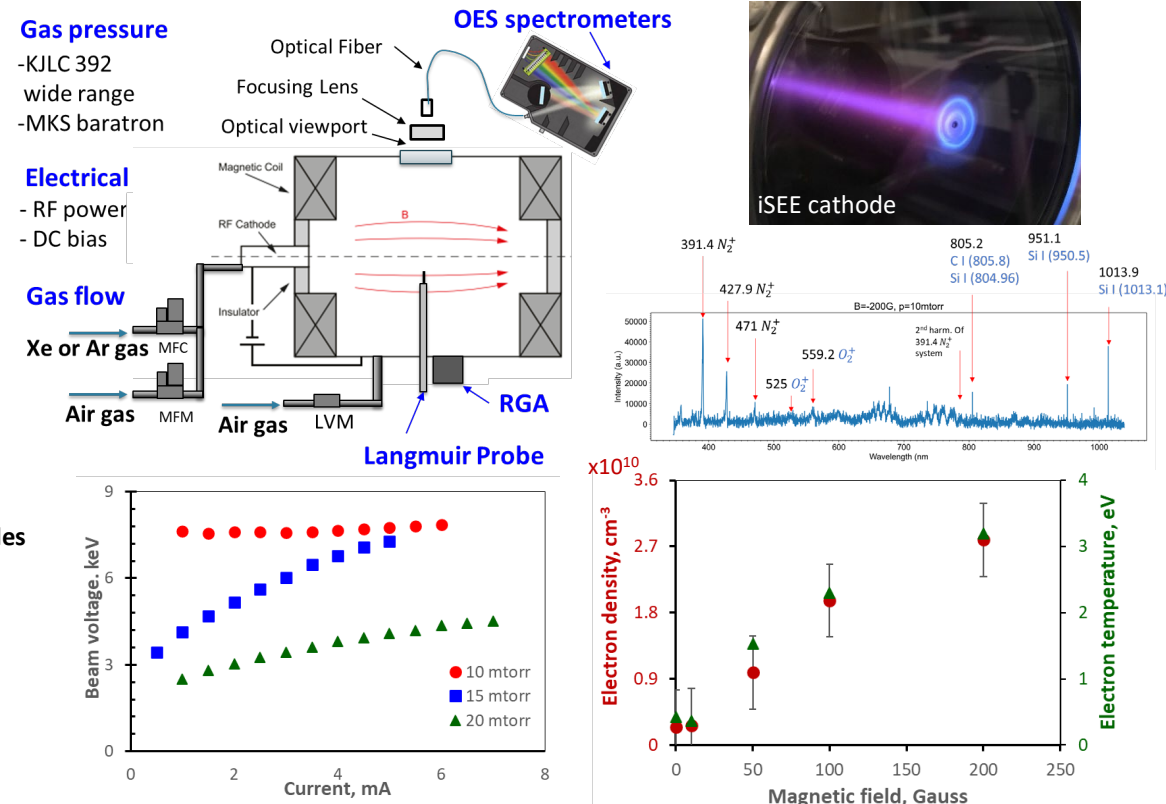


- PIC simulations shows onset of modulation instability and the development of plasma turbulence that can scatter the electron beam.



Experiments

- Explored operation of electron-beam generated air plasma at low pressures ($< 10^{-2}$ torr) in the Penning system with different cathodes (ion-induced SEE, thermionic, RF cathode)



- A simplest iSEE cathode for e-beam is an attractive option but with standard materials, can not sustain the required ionization for the drag compensation.
- RF cathode can sustain high ionization but needs additional gas to operate.
- e-Beam from both cathodes propagate along the whole 0.5 m length chamber.
- Plasma composition: molecular ions, measured gas temperature ~ 300 K.

What needs to be done in order to meet or further the goals?



- **Year 2: Develop understanding and predict power and particle balances in the airbreathing thruster with operating conditions (pressure $<10^{-5}$ torr) relevant to the targeted altitudes of above 130-200 km:**
 - Advance a global plasma model with focus on the relevant air plasma chemistry, accounting for the incoming air flow, and with application to a specific thruster design and pressures.
 - Complete plasma characterization of beam-generated air plasmas with magnetic cusp(s) without the inlet flow to compare and validate with predictions of the global model (chemical composition, macroscopic plasma and discharge parameters).
- **Year 2: Initial optimization of the thruster operation including i) required electron beam properties (e.g., energy distribution, penetration depth) to sustain ionization, and iii) ion acceleration & neutralization:**
 - Conduct 2D PIC simulations of one specific thruster configuration.
 - Measure beam-plasma kinetic properties to validate PIC simulations and initiate experiments on the ion acceleration and the thruster performance measurements at pressures of less than 10^{-5} torr.
- **Future goals: suitable cathode materials, realistic inlet flow (7-8 km/s), and design optimization:**
 - Explore e-beam sources and cathodes (thermionic, field emission, and high SEE) capable to withstand harsh plasma environments relevant to the airbreathing application (ion bombardment and reactive chemistry).
 - Develop and demonstrate in experiments, the generation of the required inlet air velocities at < 10 mtorr.
 - Thruster design optimization (e.g., magnetic field topology) with the full scale 2-D and 3-D PIC.
 - Comprehensive experimental characterization and optimization of the airbreathing thruster with the inlet flow.