APPLICATION NOTE [LP04]

Hall Effect Thruster plasma plume characterization with probe measurements and self-similar fluid models*

STUDY

Hall effect thrusters (HET) are currently recognized as a good propulsion means for long missions and moves that require large velocity increments. The plasma plume of a HET exhibits a relatively large divergence angle of about 45°, and investigating this plume and its expansion into space is vital for understanding these devices and assessing the mechanical and electrical interactions of the exhaust plasma plume with the spacecraft itself and the surrounding environment.

PRELIMINARY

Understanding the dependence of the plume evolution with the main operating parameters also allows to:
(1) optimize thruster design for maximum performance,
(2) reduce potential interaction hazards,
(3) produce a tailored plasma jet for advanced applications, such as the recently introduced Ion Beam Shepherd system.

However, analysis of electric propulsion plasma plumes is difficult, due to the complexity and number of phenomena taking place in the plume formation and downstream expansion. Usually, a combination of ground testing, in-space measurements and modelling must be used to correctly describe the plume. However, in this study, the authors employed a cylindrical probe, a simple and versatile diagnostic tool, to study the plasma plumes generated by two different HETs. They then used semi-analytical, self-similar fluid models of the hypersonic far-field plasma plume to fit and assimilate the experimental data from the probe, in order to recover features such as the shape of ion streamtubes.

METHOD

A single cylindrical Langmuir probe was used to investigate the electron properties (Φ, Te and n) in the far-field plumes of the two HETs, namely the 1.5kW PPS 100-ML and the 200W PPI thruster. The probe was inserted as illustrated in the following diagram:

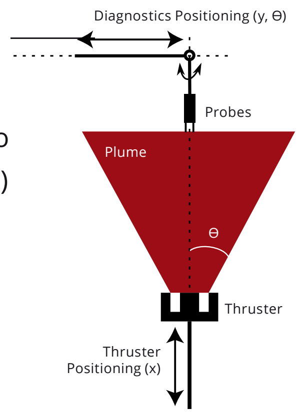

Figure 1: Schematic view of the HET and probe positioning system

FINDINGS

The results of the study show that these plasma properties decrease with the distance from the thruster exit plane and the thruster axis as the hypersonic plasma plume expands into the vacuum. A self-similar fluid model of the plasma plume that depends on the Mach number M_0, the initial streamline divergence rate h'_0, the polytropic constant γ, and the initial profile width was then used to fit the experimental data. The authors then used the model to obtain the flow direction and a downstream extrapolation of the different plasma properties outside the measurement region. Experimental data and numerical models demonstrate good agreement.

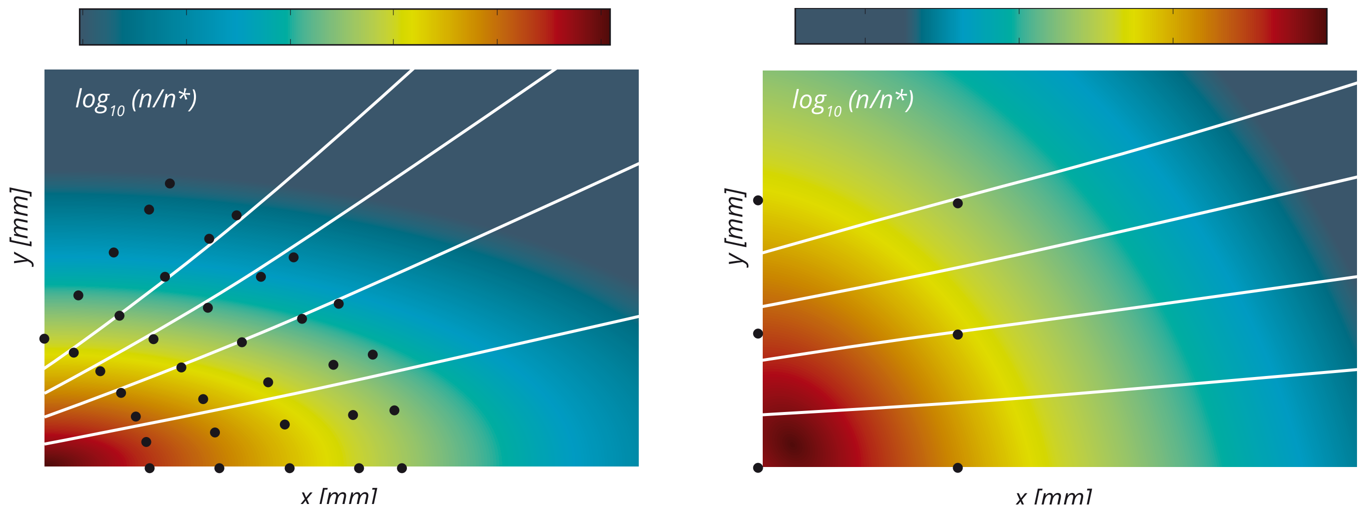

Figure 2: Plasma density maps in the plasma plume of the PPS 100-ML thruster at 300V (left) and the PPI thruster at 225V (right). The position of the measurement points is displayed with black dots. Selected ion streamlines are drawn in white. The normalised value presented here is $\log_{10} n/n^*$, where n^* is the density at the first measurement point (i.e. the leftmost measurement point in the figures; $2.98 \cdot 10^{15}\ m^{-3}$ for the PPS 100-ML, $1.65 \cdot 10^{16}\ m^{-3}$ for the PPI. The thruster exit section is located at $x=0$. The model initial section has been located at the position of the first (leftmost) measurement point. Notice that figure is not in 1:1 ratio for practical reasons.

STUDY USES

The study shows that a single cylindrical Langmuir probe can provide a simple characterisation of the plasma plume of Hall effect thrusters, which can be used as a tool for preliminary thruster optimisation.

REFERENCES:

* K. Dannenmayer and S. Mazouffre, ICARE - CNRS, Orléans 45071 France. M. Merino and E. Ahedo, Universidad Politécnica de Madrid, Madrid 28040 Spain. arc.aiaa.org/doi/abs/10.2514/6.2012-4117