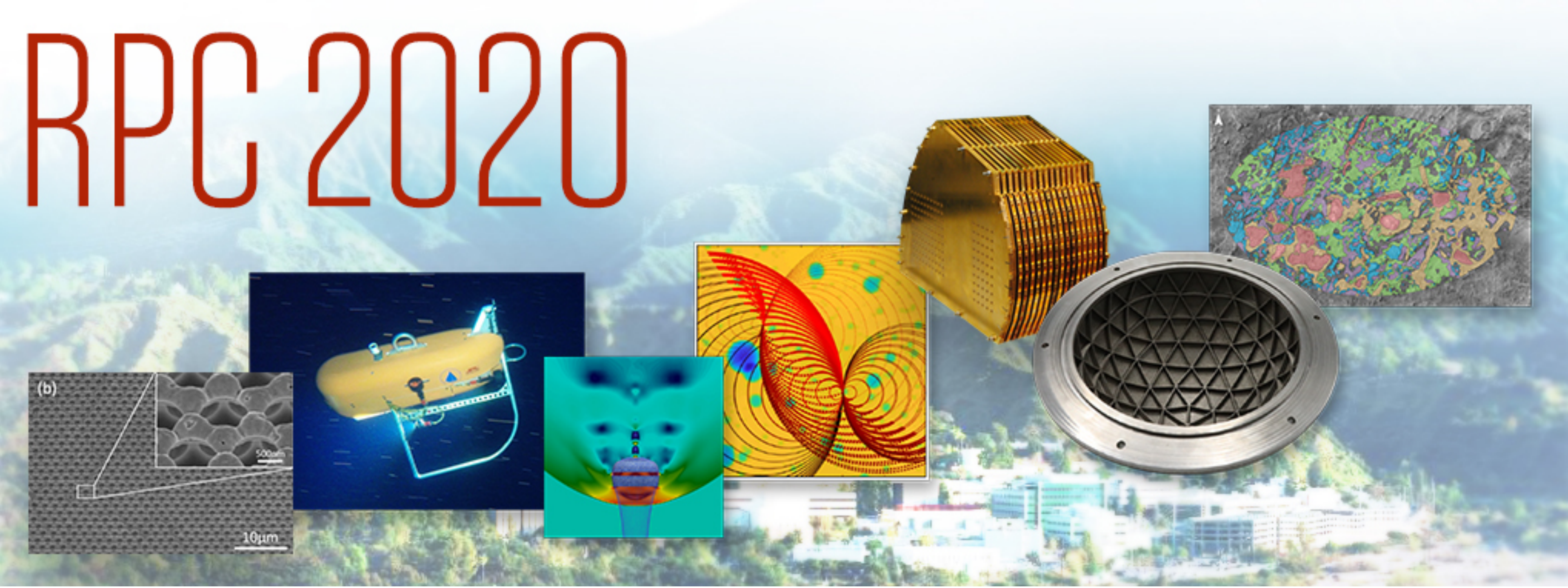

Virtual Research Presentation Conference

Hall Thruster Stability at Low Power and High Specific Impulse

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Program: SURP

Assigned Presentation #RPC-239

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Abstract

The high specific impulse of magnetically-shielded Hall thrusters when operated at high voltage (> 500 V) is an enabling feature for deep space missions. However, while it is possible to achieve efficient and stable operation at high specific impulse over a nominal power range, it has been found that when the power drops below a certain threshold (typically <50% of nominal), shielded thrusters will transition into a highly oscillatory state. This transition is a particular problem for deep space applications where the power level drops with solar range.

The goal of this collaboration is to overcome this limitation by demonstrating the ability to operate stably at low power and high-specific impulse. By leveraging the talented students and world-class facilities at the University of Michigan, the key objectives are to investigate, explain, predict and mitigate the onset of this transition.

Year 1 focused on characterizing the transition to instability for various operating conditions. In parallel, a data-driven approach has been explored in search of simple models for describing the oscillations. Both activities have laid the foundation for Year 2 in which a physics-based study will be performed to describe the nature of the unstable mode.

9-kW class magnetically shielded Hall thruster operating at University of Michigan at 600 V and 33% nominal power

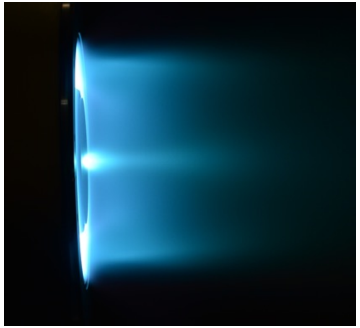
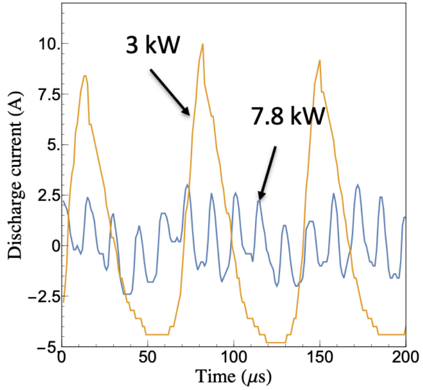


Illustration of mode transition to higher oscillations in discharge current when thruster drops to low power



Methodology

Phase I: Mapping the parameter space: The goal of this phase is to characterize the current oscillations in a laboratory-model magnetically shielded Hall thruster and to generate a detailed map of how the design parameters (flow rate, magnetic field strength, etc.) correlate to the transition to instability.

Phase II: Detailed characterization of the unstable modes: The purpose of this phase is to measure the plasma properties of the thruster as it transitions to the oscillatory mode. Key goals are to identify where the oscillations originate in the thruster, to characterize the local plasma environment in this region, and to measure phase relationship and amplitudes between the various local plasma properties. This data will inform a first-principles investigation into the mode transition in Phase III.

Phase III Numerical and analytical investigation: The goal of this phase is to classify the mode transition, its energy source, and the stability criteria for its onset. This will be done in two parallel but complementary ways. The first is a data-driven approach in which Bayesian inference is applied to discover governing equations for the oscillations. This has the advantage of being able to work on limited data sources (i.e. only measurements of the discharge current) while yielding insight into the key design parameters that drive the transition. The second method is to use the detailed experimental measurements in Phase II to guide a linear perturbation analysis. We have applied a similar approach in our previous studies of large-scale oscillations in Hall thrusters [6-7]. With a first-principles, validated model for the mode transition, we will know the physical processes that drive the mode change. This insight in turn will be used to modify JPL's state of the art Hall thruster code, Hall2De, to model the transition.

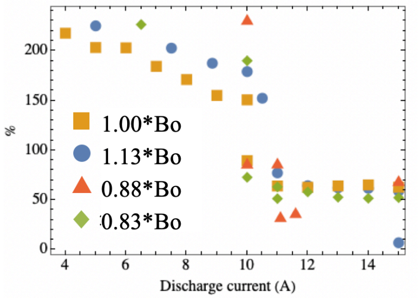
Phase IV: Prediction and mitigation: In this last phase, which is planned to occur in Year 3, we will leverage the tools and criteria developed in Phase III to demonstrate the ability to predict the mode transition and explore methods to mitigate it.

Results

Map of the transition

- At 600 V operating condition, measured oscillations in thruster discharge current as function of time-averaged current at different magnetic field intensities
- Found evidence of stark transition to unstable below at currents below ~10 A

Amplitude of oscillations as function of discharge current

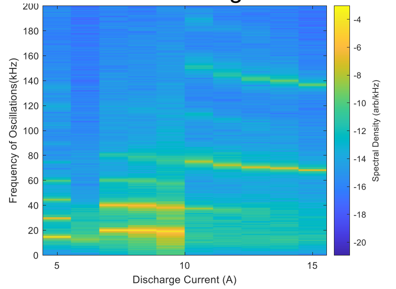


Significance: map provides unprecedented level of detail documenting how design parameters impact transition

Insight into nature of instability

- Parametric plot of power spectra shows oscillations have fundamentally different nature before and after transition point
- At high currents, modes are low amplitude and rotational, originating at the cathode. In the unstable mode, the oscillations are cnoidal and originating in the discharge chamber.

Power spectra of oscillations as function of discharge current

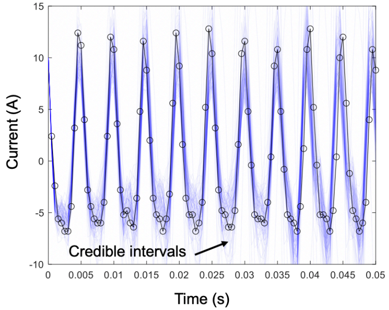


Significance: Provides critical clues about the nature of the mode and the processes that drive it unstable. These can be leveraged to identify mitigation techniques

Data-driven model for instability

- Developed a data-driven model based on a linear-state space in time delay coordinates
- Calibrated model against data and showed that it can match with a high degree of accuracy experimental results. Also showed ability of model to represent oscillations before and after transition

Comparison of experimental and data-driven model fit



Significance: Demonstrates complementary and potentially alternative path for deriving stability criteria and mitigation techniques for mode transition

Next steps

- Expand experimental dataset for mode transition to different voltages and cathode flow fractions
- Perform experimental characterization of plasma properties during mode transition focusing on relative amplitudes and phases
- Attempt to use experimental data to inform analytical model for stability
- Continue to explore data-driven model to also arrive at predictive stability criteria for mode transition
- Leverage insights to identify mitigation techniques

References

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Publications

Abstract for this work are planned for presentation at either the 2021 Space Propulsion Conference or the 2021 International Electric Propulsion Conference.