Background

Hall thrusters are a type of electric space propulsion that is increasingly used for Earth orbit and deep space missions. A Hall thruster uses crossed electric and magnetic fields to sustain a plasma and accelerate ions out of the device, producing thrust. Hall thrusters are very efficient, with exit velocities ~10 km/s for xenon propellant, but produce low thrust, ~100 mN. Although these devices have been studied and flown extensively, there are no self-consistent simulations of them. One phenomenon that is not completely understood is the ubiquitous “breathing mode”: strong ~10 kHz oscillations in discharge current and other global parameters.

The breathing mode has been recovered by simulation [1] and characterized experimentally [2], but analytical approaches have yielded neither an intuitive explanation of the underlying physical mechanisms nor any criteria for instability [3].

Objectives

The breathing mode is sensitive to many operating parameters and may have large-scale effects on the thruster operation, for instance by playing a role in thruster erosion. Yet there are still many shortcomings with the modern understanding:

- Simulation: not predictive, not validated
- Experiment: impractical, unrealistic
- Theory: no intuitive criteria
- What is the energy source?
- What are the instability criteria?

Governing Equations

The stability of different subsets of the governing equations is judged by performing numerical (nonlinear) simulations and a linear perturbation analysis. A positive linear growth rate γ is desired.

Table 1: Combinations of perturbed quantities explored for 0D modeling.

<table>
<thead>
<tr>
<th>Perturbed Quantity</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>j</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>j0</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>E</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Lx</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Results

The stability of different subsets of the governing equations is judged by performing numerical (nonlinear) simulations and a linear perturbation analysis. A positive linear growth rate γ is desired.

Conclusions

1. Zero-dimensional models can capture growing oscillations similar to the breathing mode.
2. The current model may be incomplete: no useful criteria for instability are presented, and the real frequency cannot be predicted.
3. 1D effects may need to be introduced to produce conditional instability.

Acknowledgments

This work was partly supported by NASA Space Technology Research Fellowship grant NNX14AL65H. Thanks to Dr. Yiangos Mikellides for directing part of this work at JPL this summer.

References