Numerical Tool for Evaluating Hall Thruster Stability

Project Objective:
The primary goal of this project was to develop a software tool to predict the onset of oscillatory modes of operation in Hall thrusters. This effort had three major milestones:

1. Determine key dispersion relations for instabilities known to exist in Hall thrusters
2. Write a user-friendly program with GUI to solve the dispersion relations from (1) for a test-case Hall thruster and output predicted instabilities
3. Validate the code against real measurements of instabilities in a Hall thruster

Benefits to NASA and JPL:
The Hall thruster is a form of electric propulsion that has been flown on over a hundred commercial systems and has been identified in the past decade as a core enabling technology for JPL’s deep space applications. These include the proposed Asteroid Robotic Redirect Mission (ARRM) as well as Psyche, a Step 2 Discovery Program mission concept. When operated optimally, Hall thrusters will run stably and efficiently for thousands of hours while offering significant payload mass savings. However, under non-optimal conditions these devices can exhibit oscillatory behavior characterized by large-scale variations in the thruster’s plasma properties and discharge power. The solution is typically generated by fixing the wavevector and searching numerically for the frequency values that correspond to roots of the dispersion relation.

Validation of PRINCE
We validated PRINCE against publically available data on the SPT-100, a 1.35 kW commercially-flown Hall thruster that operates with xenon propellant. Using experimental data sets of electron density, plasma potential, and radial magnetic field, we generated with PRINCE a spatial map of the frequencies of the oscillations associated with the Eissich-Hillian mode in the thruster channel. The relation for oscillation is:

\[ \frac{1}{(u - \omega_M)^2} + \frac{k_z^2}{k_0^2} = 0 \]

where the coordinate system and physical parameters are shown in the figure to the right. The plot of the oscillation frequencies generated by PRINCE matches estimates from a previous study on this instability in the SPT-100 channel (Choueiri, E. Y., “Plasma Oscillations in Hall Thrusters,” Physics of Plasmas, Vol. 8, No. 4, 2001, pp. 1411-1426). Moreover, it is well-known that this oscillation becomes unstable when the radial magnetic field exhibits a negative gradient. The calculated localization of the instability to this region in the thruster geometry is additional validation of the solver.

FY15/16 Results:
We developed the Plasma Rocket Instability Characterizer (PRINCE), a prototype software tool implemented in Wolfram Research’s Mathematica. PRINCE was validated by reproducing results of a previous study concerning instabilities arising in a Hall thruster channel. Major accomplishments include:

- Developed a user-friendly graphical interface featuring versatile data input, customizable solver settings, and varied data visualization options
- Implemented robust autonomous algorithms for the root-finding and root-tracking tasks
- Tested and validated PRINCE with various types of data sets and different dispersion relations

Plasma Rocket Instability Characterizer (PRINCE)

The Plasma Rocket Instability Characterizer is a numerical tool to evaluate the dispersion relations relevant to the Hall thruster. The user specifies through a GUI the dispersion relation to be solved as well as the geometry and background plasma parameters of the thruster.

Publications:

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