Investigation of Channel Interactions in a Nested Hall Thruster

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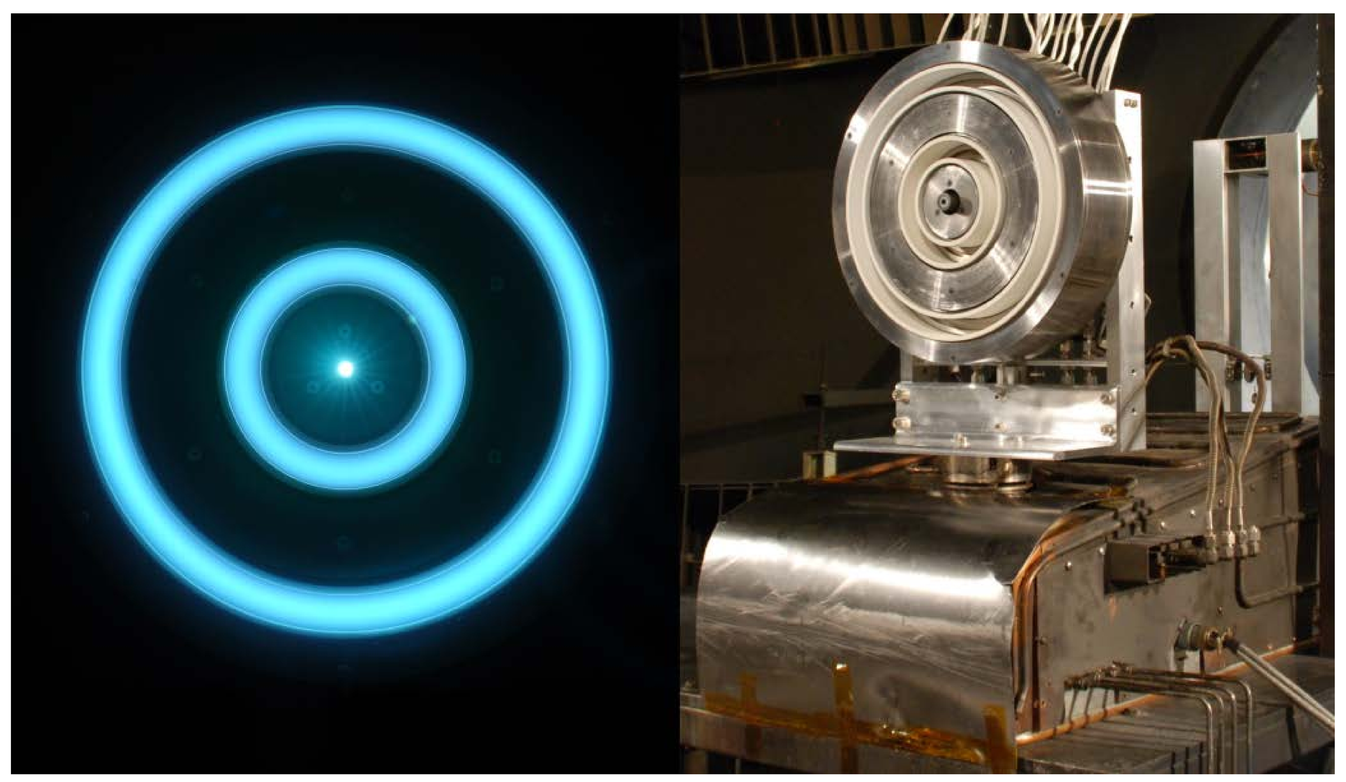
Abstract

Nested Hall thrusters, which concentrically nest multiple discharge channels together, are an attractive option for scaling Hall thrusters to high power. Their ability to maintain high thrust to power ratios, reduce mass to power ratios and throttle over large ranges makes them ideal for high power missions such as cargo missions to Mars. However, the underlying physics of how the multiple channels interact with each other and affect the device is not well understood. This study aims to understand the interactions between channels via thrust, beam current, divergence angle and laser-induced fluorescence measurements.

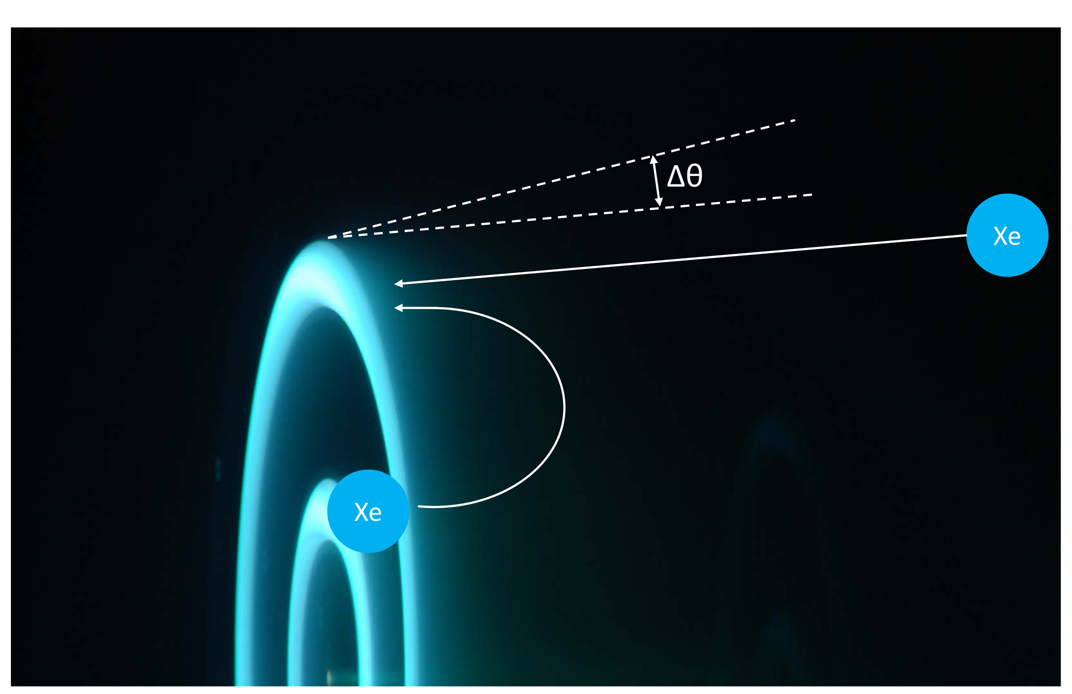
Introduction

Nested Hall thrusters, developed by the University of Michigan in conjunction with NASA and the Air Force Research Laboratory, allow the scaling of Hall thrusters to high power without large increases in mass and footprint.



Previous studies on the X2 [1], a two-channel nested Hall thruster seen above, have shown discrepancies between predicted performance in multi-channel operation based on single channel operation and actual multi-channel operation. These results suggest that the channels in a nested Hall thruster are interacting and affecting performance.

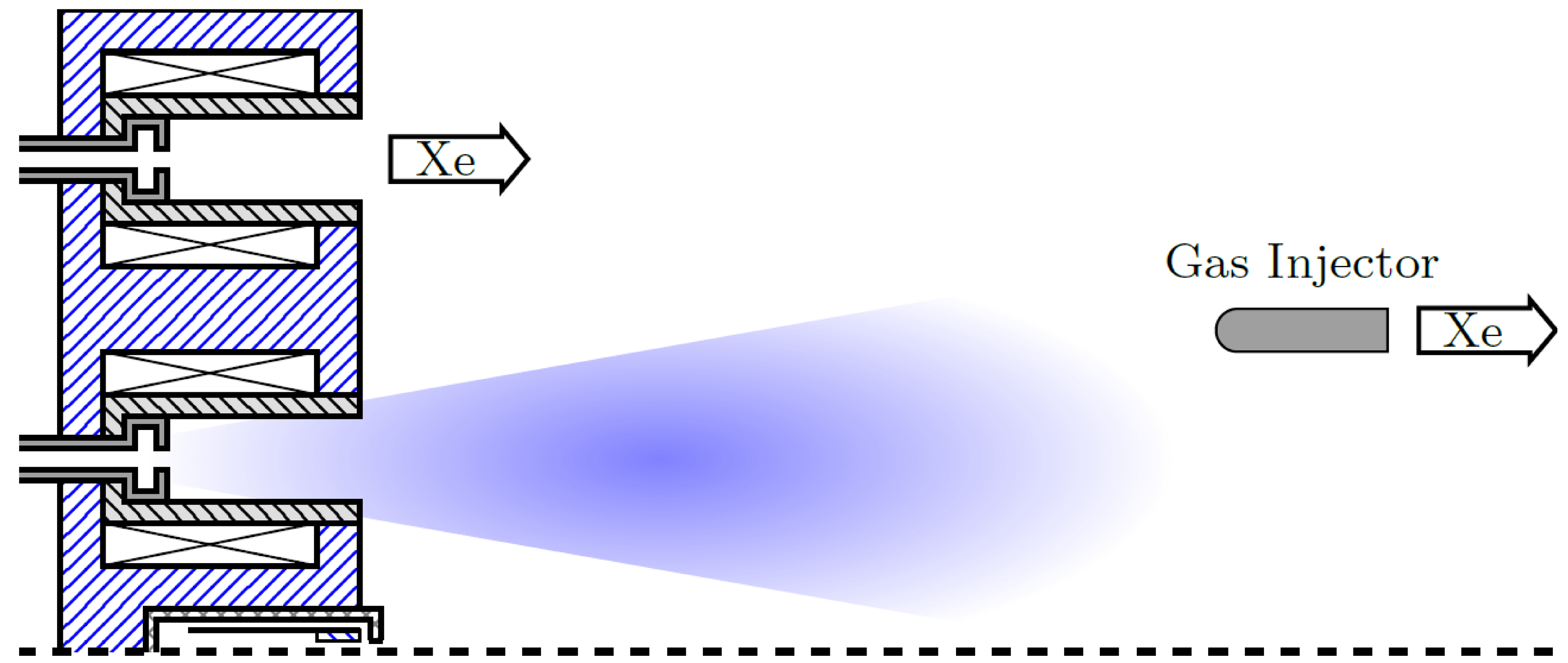
Mechanisms for Interaction



Three main theories were tested as the source of the performance discrepancy:

1) Neutral ingestion from the background due to increased background pressure
2) Neutral ingestion from the adjacent channel increasing the mass utilization
3) Divergence angle decrease increasing the efficiency of the thruster

Test Conditions

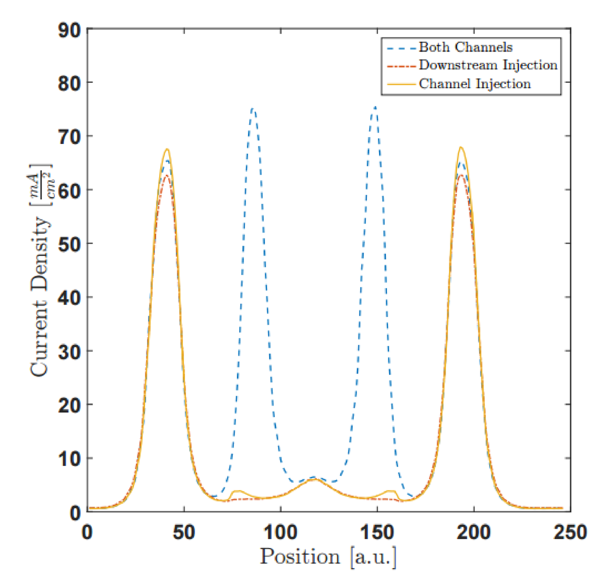


Near Field Faraday Probe

A near field Faraday probe was used to measure beam current and divergence angle using the following equations:

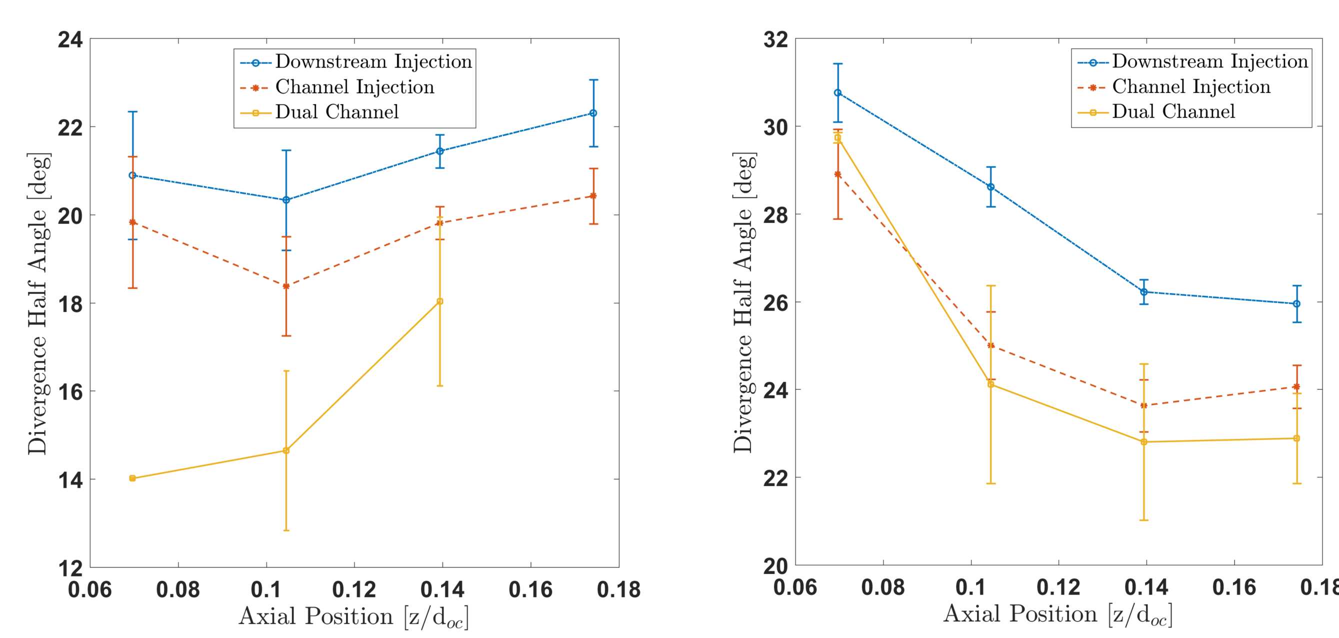
$$\theta(z) = \tan^{-1}\left(\frac{r_2 - r_{max}}{z}\right)$$

$$I_b = \int_0^{2\pi}\int_{r_1}^{r_2} j(r,z)\,r\,dr\,d\phi$$



Condition	Beam Current [A]
Dual Channel	28.34±0.35
Downstream Injection	27.78±0.10
Channel Injection	28.51±0.05

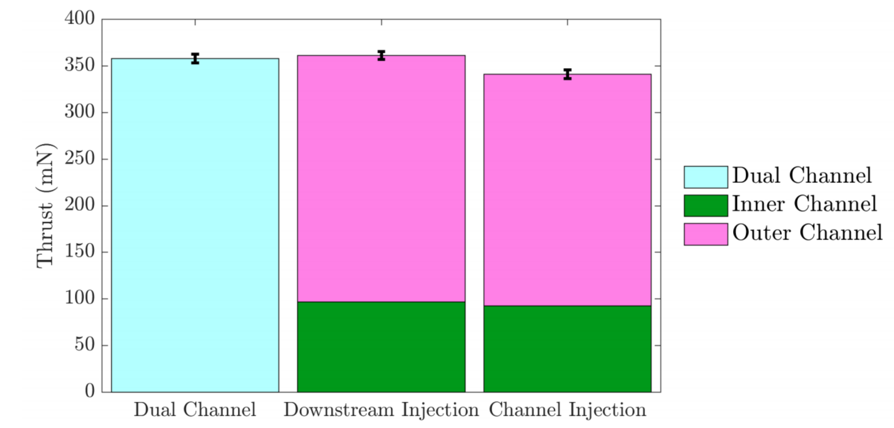
Divergence angle decreases suggests acceleration region movement and increased beam current suggests neutral ingestion.



Thruster Performance

An inverted pendulum thrust stand, was used to take thrust measurements. Efficiency and specific impulse were then calculated using:

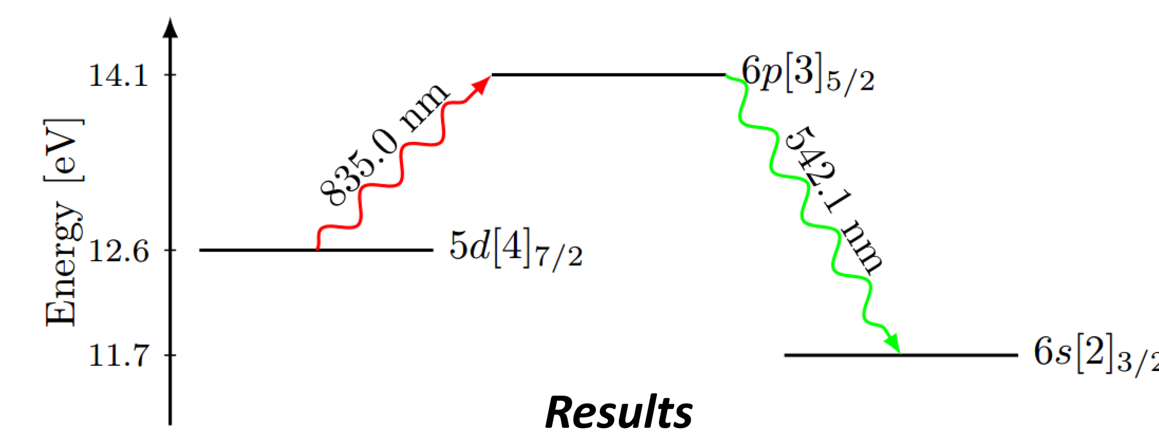
$$\eta_a = \frac{T^2}{2\dot{m}_a g} \qquad I_{sp} = \frac{T}{\dot{m}_a g}$$



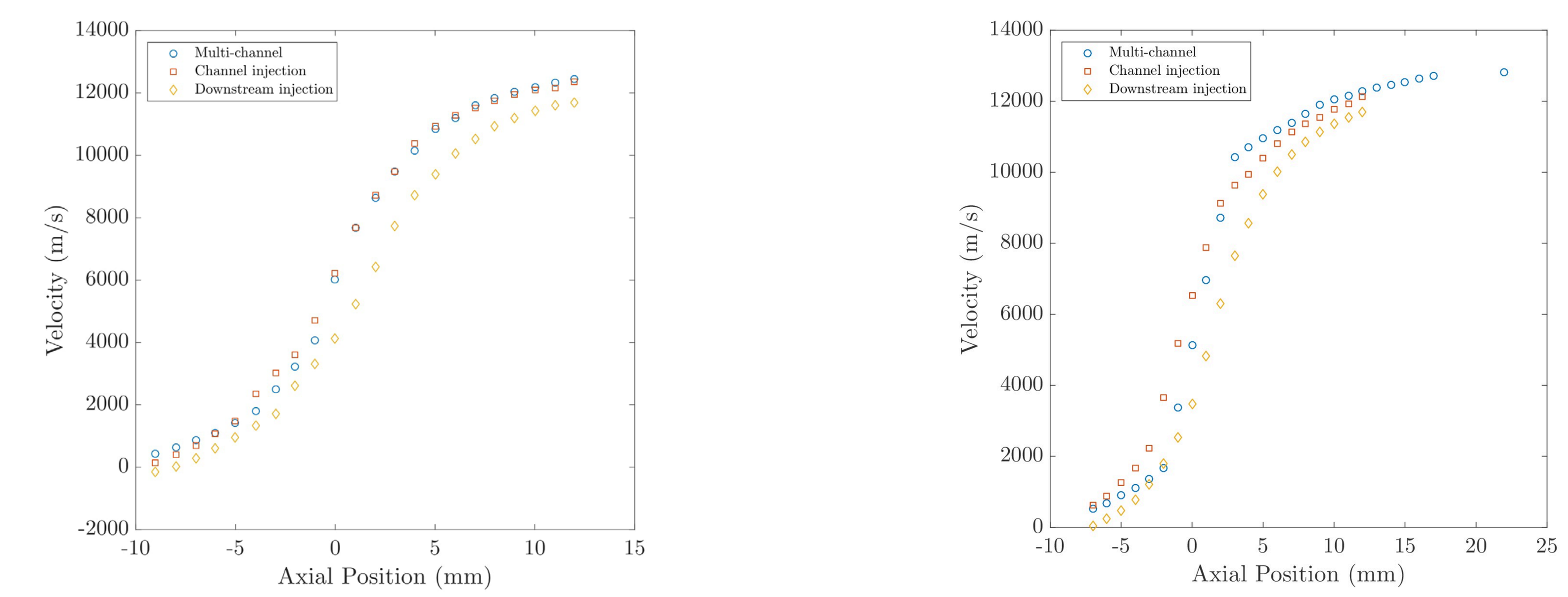
Condition	Anode Efficiency	Specific Impulse [s]
Dual Channel	0.47±0.01	1196±14
Downstream Injection	0.42±0.02	1141±33
Channel Injection	0.47±0.03	1208±36

Laser Induced Fluorescence

Laser-induced fluorescence (LIF) is a spectroscopic plasma diagnostic which can measure the ion velocity by exciting an electronic transition.



Results



LIF measurements show the acceleration region moves inward during multi-channel operation

Conclusions

Nested Hall thrusters in multi-channel operation have higher performance than expected due to a combined result of neutral ingestion from the other channel and acceleration region movement inwards resulting in lower cosine losses.

Acknowledgements and References

This research was partially funded by NASA Space Technology Research Fellowship grant number NNX15AQ43H, NNX15AQ37H, and NNX14AL65H.

1. Liang, R., "The Combination of Two Concentric Discharge Channels into a Nested Hall-Effect Thruster," Ph.D. Dissertation, University of Michigan, 2013.

7th Annual MIPSE Graduate Student Symposium, Ann Arbor, Michigan