# Preliminary Observations of Channel Interaction in a 100-kW Class Nested-channel Hall Thruster


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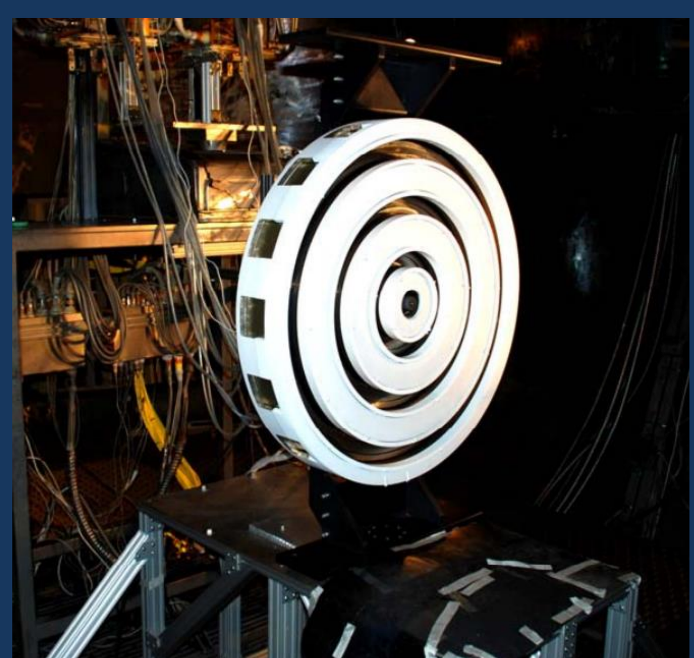
## The X3

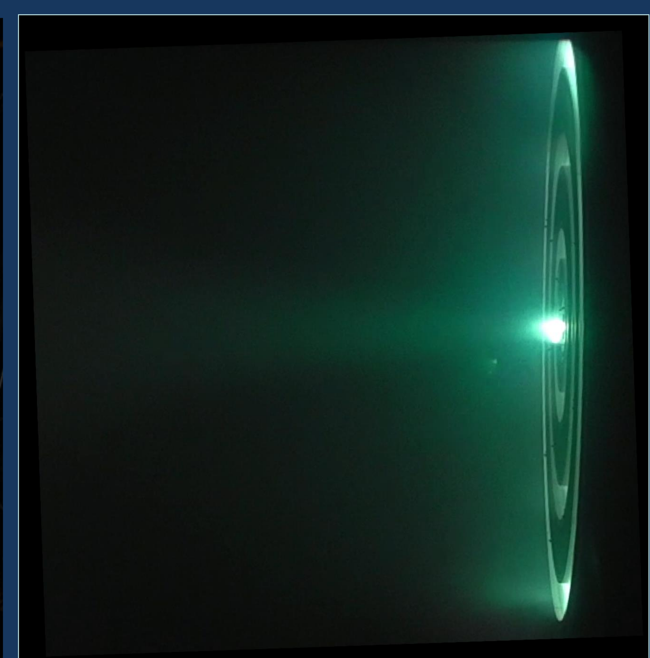
A nested channel Hall-Thruster (NHT):

- with 3 channels
- capable of 200 kW of discharge power
- weighing over 250 kg
- about 1 m in diameter
- new: fired first in Sep 2013

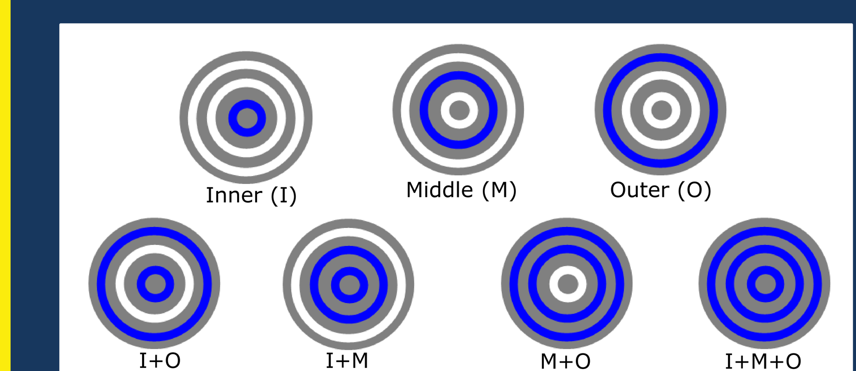
The X3 was developed jointly between the Plasmadynamics and Electric Propulsion Laboratory at the University of Michigan, NASA, and the Air Force Office of Scientific Research [1,2,3]



Prior to first firing



At 61 kW discharge power



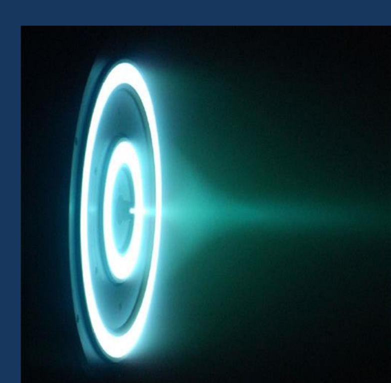

The channels of the X3 can be run separately or together, giving the thruster 7 operational modes.

## Previous Work: The X2

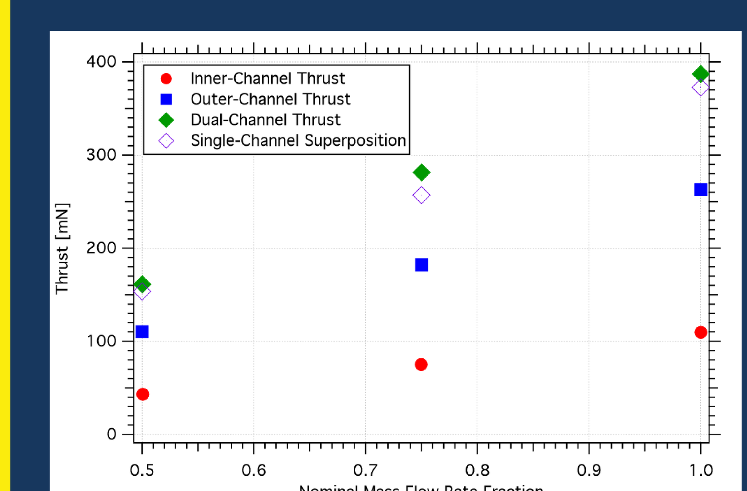
The X2 is:

- a 2-channel NHT
- capable of 6 kW of power
- a proof-of-concept thruster looking at nesting channels for the first time in open literature

Significant channel interaction was found with the X2, namely a boost in thrust when running both channels.



An operational photo of the 2-channel X2 NHT




A figure from Ray Liang's dissertation [4] showing the thrust boost seen in the X2 at constant propellant flow rate in the dual-channel mode. It was shown that this was not a facility effect and was a real phenomenon.

It is suspected that the behavior seen in the X3 is the same physical mechanism causing this behavior in the X2.

## Test Campaign

An "initial characterization" of the thruster to ensure it is running as designed. Diagnostics used:

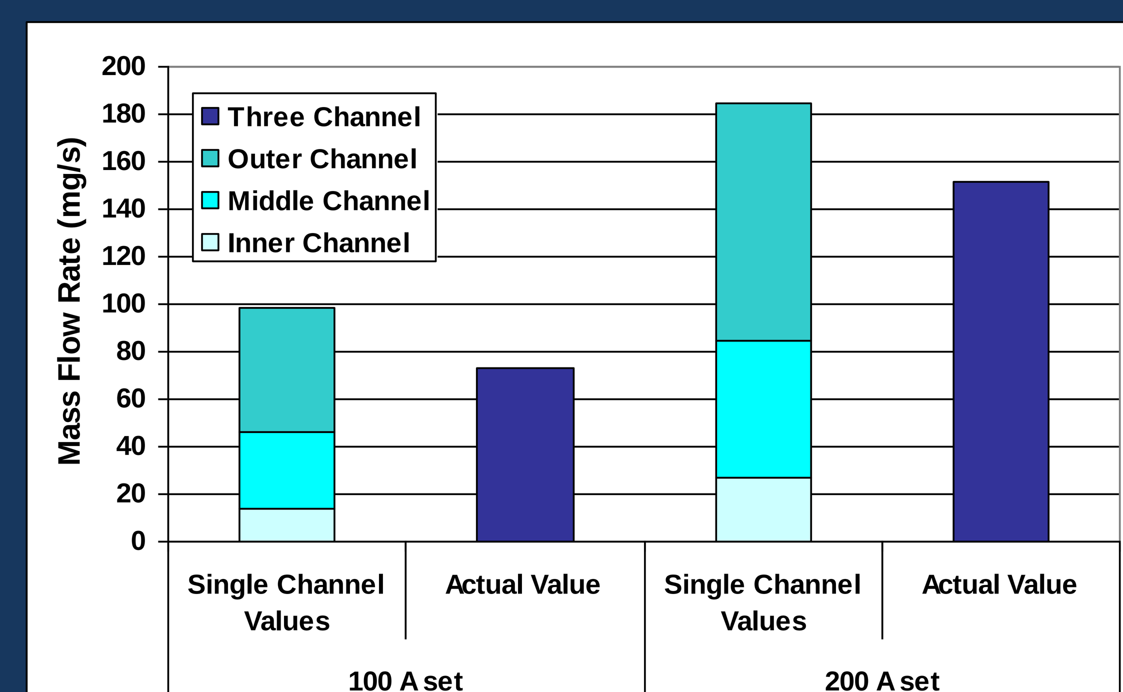
- **Photographs** to ensure plasma plume was symmetric
- **High-speed current probes** to measure oscillations in the discharge current
- **Telemetry** to study trends across thruster operating parameters, including propellant flow rates

Tests occurred in the Large Vacuum Test Facility at PEPL, a 9m long, 6 m diameter vacuum chamber capable of base pressures of 1x10$^{-7}$ Torr.

The Large Vacuum Test Facility is shown to the left with the end cap off.

## Propellant Savings in Multi-Channel Modes

Less propellant was necessary to maintain constant current density when running multiple channels of the X3 than the sum of the channels running alone.




This plot illustrates the savings seen in the 3-channel mode. The sum of the single channel values is 26% and 18% more than the actual value of propellant flow rate necessary to maintain the lower and higher current densities, respectively.

**Questions:**

- What is the mechanism causing this?
- Can this be "engineered" to; that is, can we design the next generation thruster to be even more efficient?


## Acknowledgments

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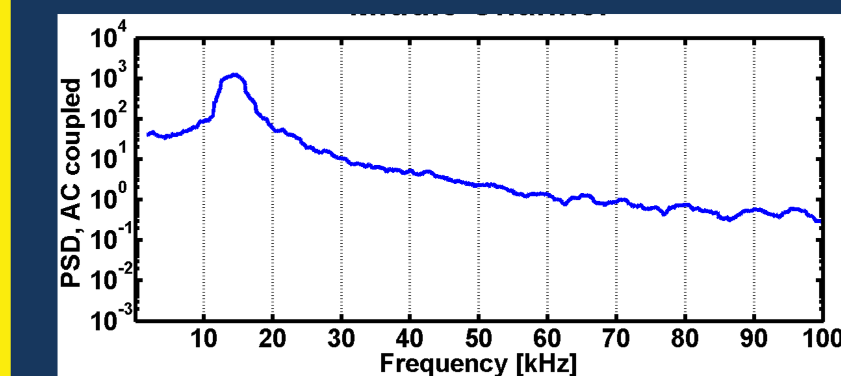
## References


[1] Florenz, R., et.al., "First Firing of a 100-kW Nested-channel Hall Thruster," IEPC-2013-394, 33rd International Electric Propulsion Conference, Washington, D.C., October 6-10, 2013.
[2] Florenz, R., "The X3 100-kW Class Nested-Channel Hall Thruster: Motivation, Implementation, and Initial Performance," Ph.D. Dissertation, University of Michigan, 2014.
[3] Hall, S., et.al., "Implementation and Initial Validation of a 100-kW Class Nested-channel Hall Thruster", AIAA 2014-3815 , 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Cleveland, OH, July 28-30, 2014.
[4] Liang, R., "The Combination of Two Concentric Discharge Channels into a Nested Hall-Effect Thruster," Ph.D. Dissertation, University of Michigan, 2013.


## Channel Interaction via Discharge Current

Power spectral densities (PSDs) of channel discharge current reveal more evidence of channel interaction. A typical power spectral density is shown below.

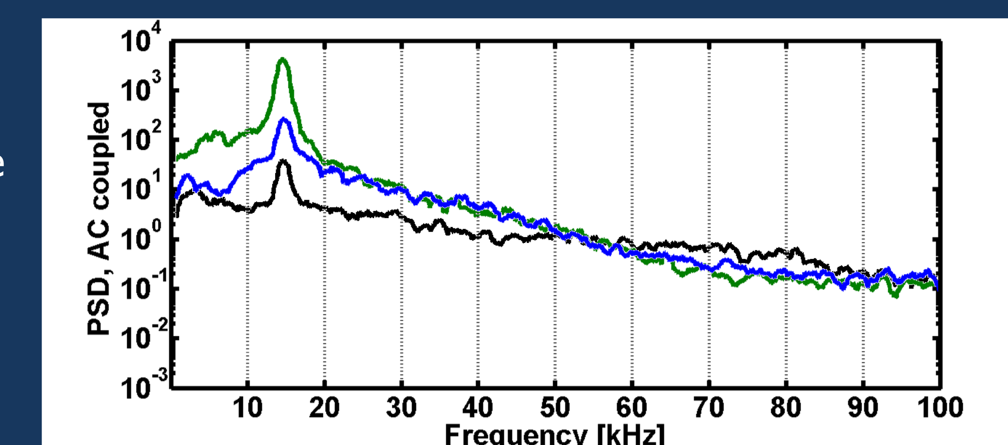



A peak around 10 kHz is normal. This is the thruster **breathing mode**, the frequency at which the discharge current oscillates.

## Breathing Modes Tend to Converge in Multi-Channel Operation

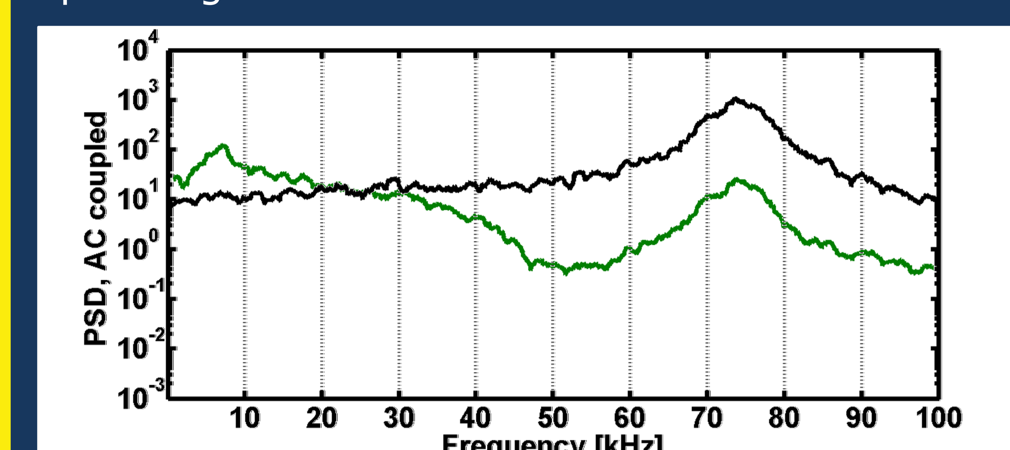
When operating together, the breathing modes of channels tend to converge to a single value. This is especially noticeable in 3-channel modes, as shown below.

For this 3-channel mode (61 kW), the breathing modes all converge to 14.7 kHz from their single-channel values.




## Anomalies in A Channel Show Through to Other Channels

Anomalies in a channel tend to leak through to the PSDs of other channels operating at the same time.




In this plot, the inner channel (black) shows no breathing mode and a large, broad spike at 73 kHz. This anomalous high-frequency spike appears in the PSD for the outer channel (green) as well.

Questions:

- How are these phenomena related to the propellant savings?
- When the breathing modes converge, is the thruster oscillating as a single unit?
- What caused the 73 kHz anomaly in the inner channel as shown?

## Conclusions and Future Work

The plan for the X3 moving forward is to:

- Get to 200 kW discharge power, following the same "initial characterization" done here
- Do a full characterization, including plasma plume studies and thrust measurements
- Work in tandem with a modeler to fully capture the physics of the plasma