High-Power Performance of a Nested Hall Thruster

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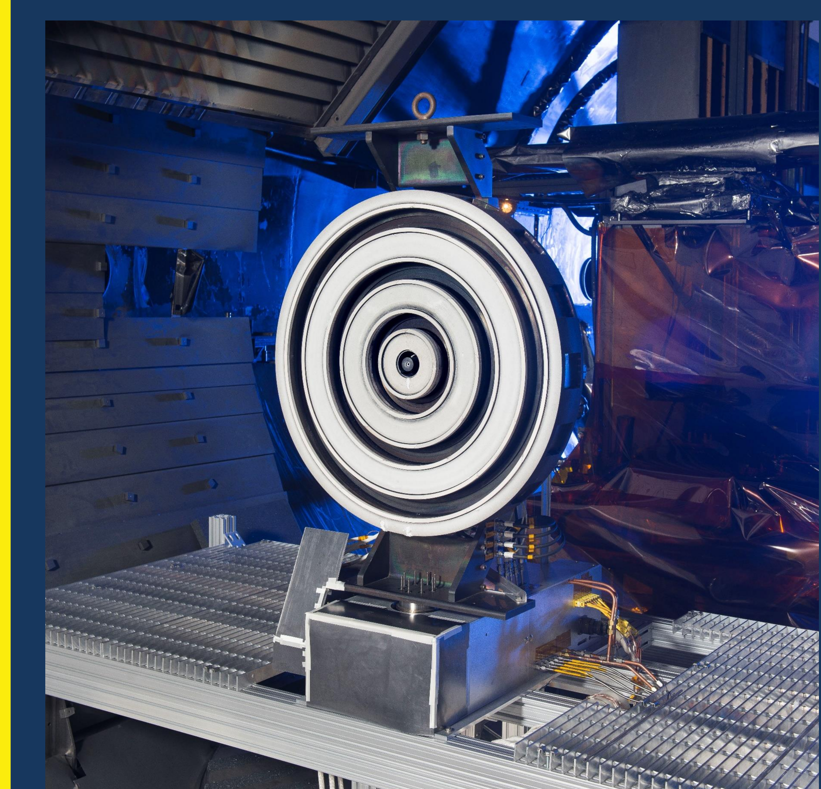
THE X3 NESTED HALL THRUSTER

A state-of-the-art nested-channel Hall thruster:

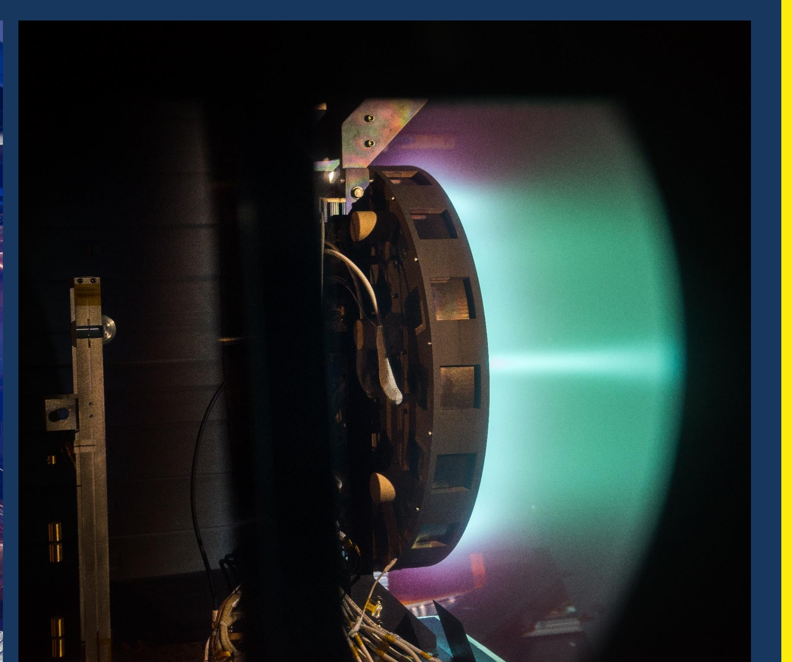
- with 3 channels
- capable of 200 kW of discharge power
- with a throttling range of 100x: can operate down to 2 kW
- weighing almost 250 kg
- close to 1 m in diameter
- first fired in September 2013

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 [1-4].

The X3 was operated at powers from 5—102 kW at NASA Glenn Research Center (GRC) in Cleveland, OH. Across that range, its performance was characterized and its plasma plume studied.



The X3 mounted in Vacuum Facility 5 at NASA GRC.



The X3 operational at 50 kW discharge power with all 3 channels operating at NASA GRC.

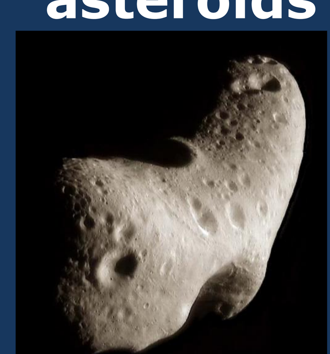
MOTIVATION

Electric propulsion systems of power levels in excess of 300 kW enable a wide variety of missions. Modeling work has shown that 50—100 kW thrusters are an optimum size for these types of systems [5,6].

Earth orbit transfer

200 kW @ 1500 s: LEO to GEO transfer

Near-Earth asteroids



300 kW @ 1800 s: cargo

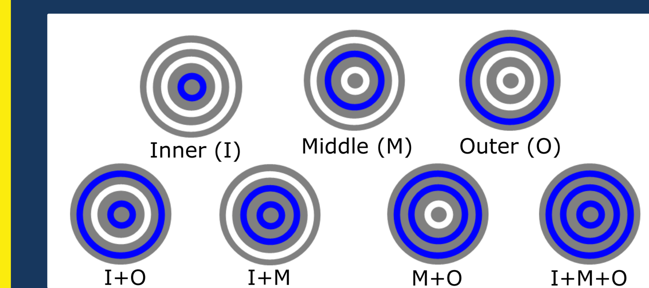
Phobos

300 kW @ 3000 s: cargo
700 kW @ 1800 s: humans

Mars

600 kW @ 3000 s: cargo
800 kW @ 1800 s: humans

THROTTLE TABLE



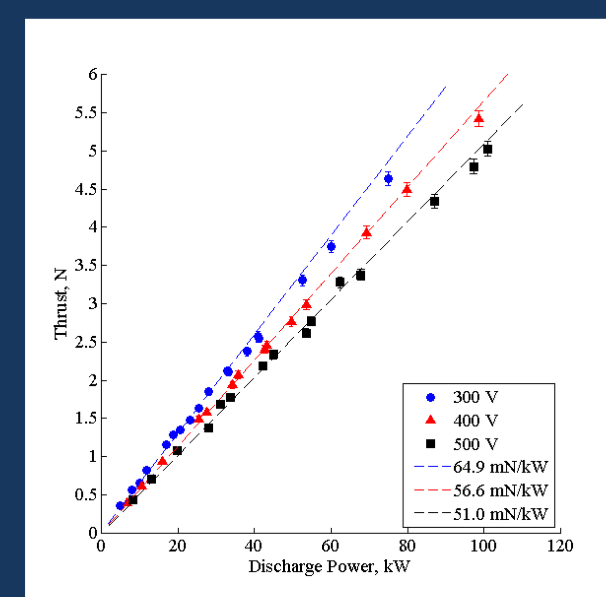
The channels of the X3 can be fired separately or together, giving the thruster 7 modes of operation, as illustrated here.

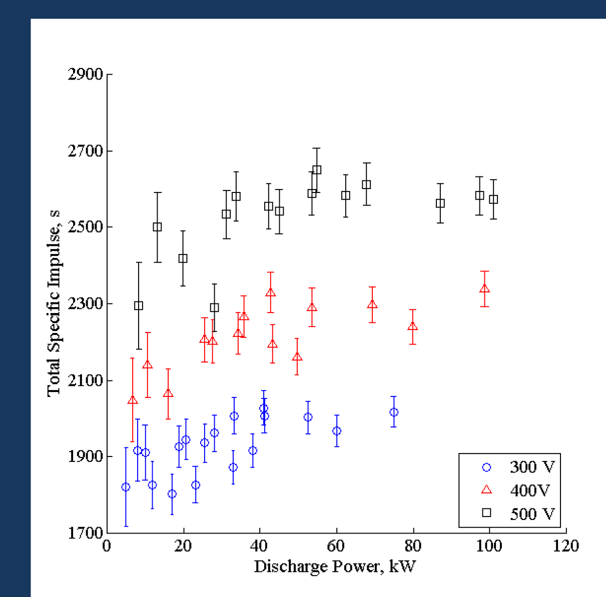
We fired the thruster in 8 combinations of discharge voltage and current density.

300 V	400 V	500 V
0.6 j_{ref}	0.6 j_{ref}	0.6 j_{ref}
1.0 j_{ref}	1.0 j_{ref}	1.0 j_{ref}
1.3 j_{ref}**	1.3 j_{ref}**	

PERFORMANCE CHARACTERIZATION

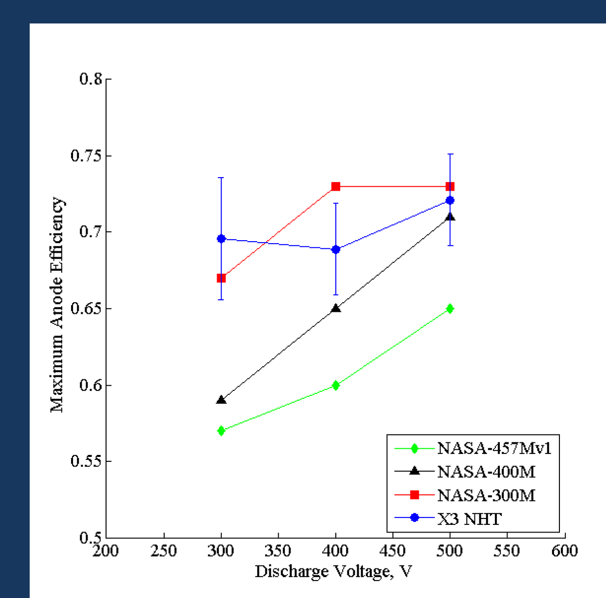
Thrust and specific impulse (below) showed expected trends for all operating conditions and discharge voltages, indicating the X3 operates as expected.





Anode efficiency (right) shows that the X3 builds off of physical insight and lessons learned from previous NASA high-power thrusters to deliver state-of-the-art values for the voltages tested [7-9]

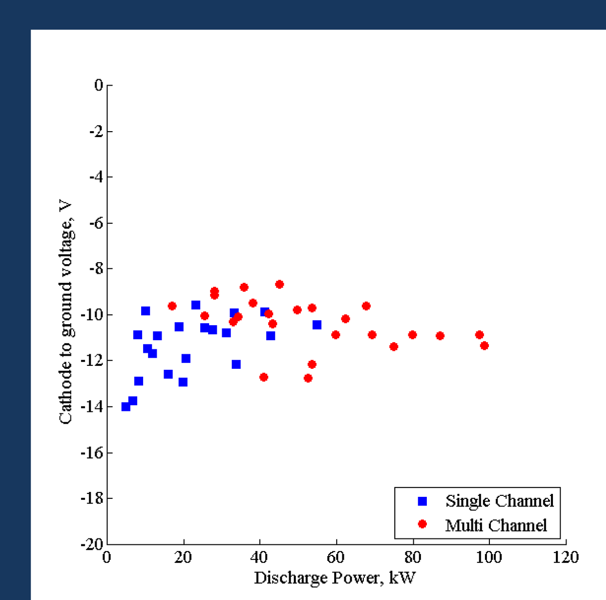
Comparisons of other performance metrics show similar trends.



CATHODE COUPLING

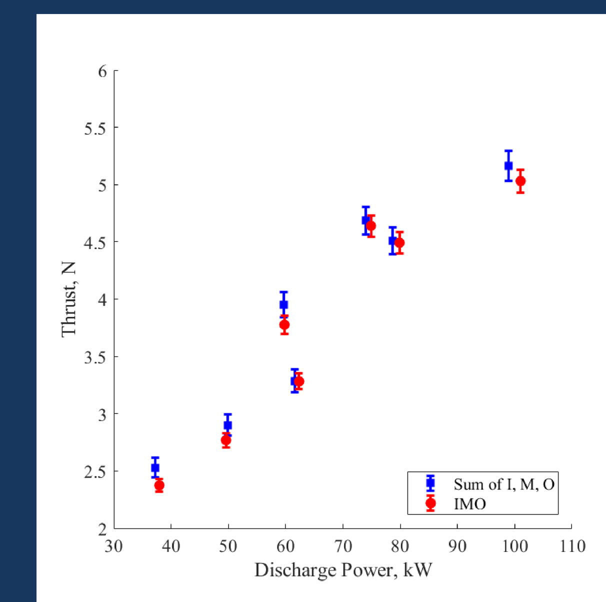
A concern with nested thrusters (and with the large outer channel of the X3 on its own) was whether proper cathode coupling could be established.

As evidenced by the cathode-to-ground voltage (right), no significant difference in cathode coupling was seen for different channel combinations or operating conditions.

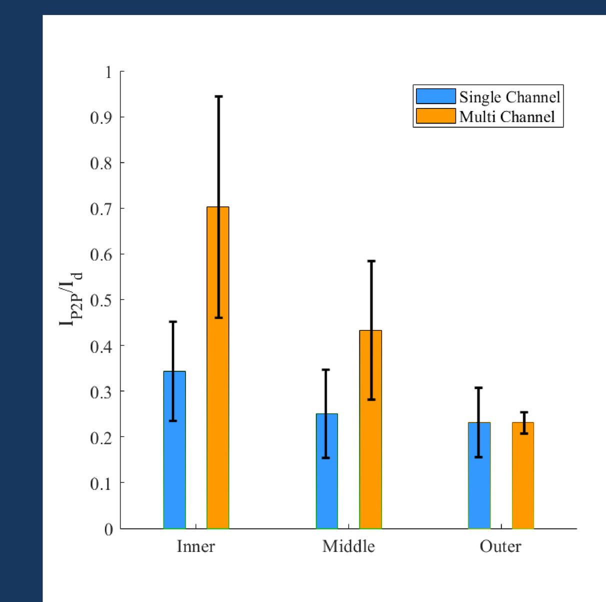


CHANNEL INTERACTIONS

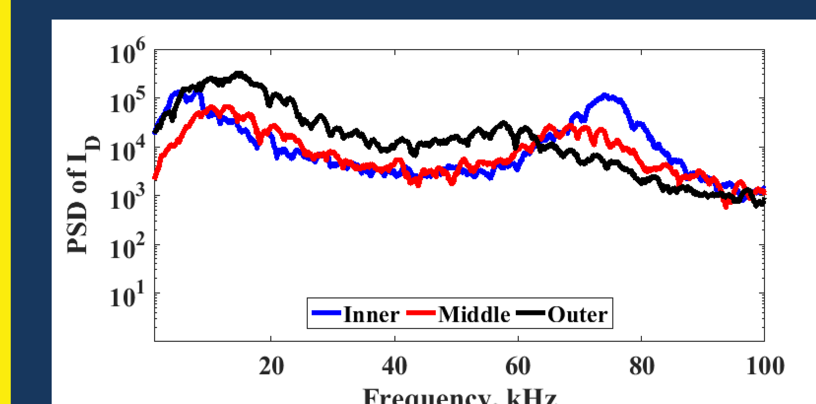
This test provided important preliminary data on channel interactions, though more work is still needed to fully understand the phenomena.



The thrust of multi-channel operation was simply the sum of individual channels, which differs from previous nested thruster results



Current oscillations changed dramatically for I and M between single- and multi-channel operation.



Power spectral densities of discharge current show:

1. Channels sometimes oscillate together
2. A high-frequency (cathode related?) peak that differs in frequency and strength between channels

CONCLUSIONS & FUTURE WORK

96 kW @ 3460 s (η_t=0.58) | 112 A | 3.3 N

102 kW @ 2400-2600 s (η_t=0.63) | 247 A | 5.4 N

The X3 has set 3 new records for Hall thruster operation. It is paving the way for cargo and crew transport to places like near-Earth asteroids and Mars. Future work will continue to push the power and performance capabilities of the thruster.

ACKNOWLEDGMENTS

This work was supported by a NASA Space Technology Research Fellowship under grant NNX14AL67H, the NASA Space Technology for Exploration Partnerships program under grant NNH16CP17C, and a Michigan Institute of Plasma Science and Engineering Graduate Fellowship.

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