30-kW, Constant-Current-Density Performance of a 100-kW-class Nested Hall Thruster

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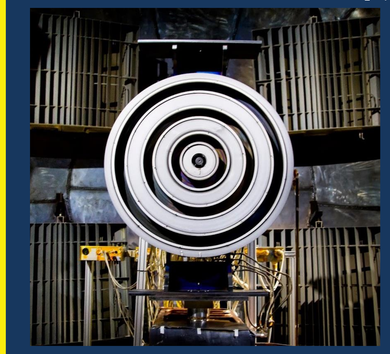
THE X3 NESTED HALL THRUSTER

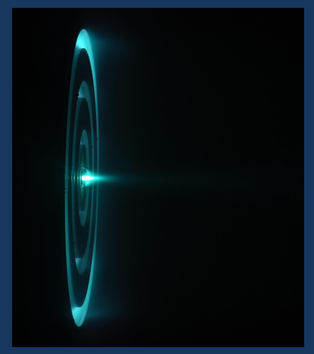
A state-of-the-art nested-channel Hall thruster:

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

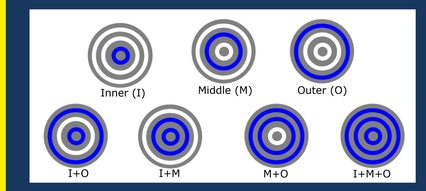
The X3 was developed jointly between the Plasmadynamics and Electric Propulsion Laboratory at the University of Michigan, NASA, and the Air Force Office of Scientific Research [1,2,3].



The X3 mounted in the Large Vacuum Test Facility at the University of Michigan



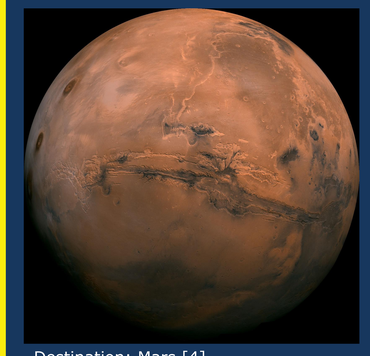
The X3 operational at 30 kW discharge power with all 3 channels operating



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

MOTIVATION

Scaling Hall thrusters to high power in this manner expands not only the maximum power but the throttling range of the device. It also relies on existing, proven, flight-rated technology, which is vital to lowering risk.



Destination: Mars [4]

The ultimate goal is Mars. A 200-kW-level propulsion device, operating at the X3-level efficiency (>60 %) and specific impulse (>3,000 s), could alone carry 20,000 kg to Mars. A system of many clustered together, reaching total system power levels in the MW range, could transport humans to Mars in a few months.

THROTTLING TABLE

For this experiment, the X3 was fired at seven different operating conditions, shown below. The thruster was operated at a constant current density of 75% of the nominal value. All conditions were at 300 V anode potential and xenon propellant, and the cathode was run at a constant flow fraction of 10%.

CONDITION	INNER DISCHARGE CURRENT	MIDDLE DISCHARGE CURRENT	OUTER DISCHARGE CURRENT	TOTAL DISCHARGE CURRENT	TOTAL DISCHARGE POWER
I	13.5 A	--	--	13.5 A	4.1 kW
M	--	31.5 A	--	31.5 A	9.5 kW
O	--	--	54.8 A	54.8 A	16.4 kW
I+M	13.5 A	31.5 A	--	45. 0 A	13.6 kW
I+O	13.5 A	--	54.8 A	68.3 A	20.5 kW
M+O	--	31.5 A	54.8 A	86.3 A	25.9 kW
I+M+O	13.5 A	31.5 A	54.8 A	100 A	30.0 kW

PERFORMANCE

Three performance metrics were analyzed in this experiment:

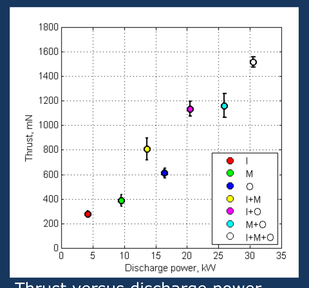
- Thrust, which was measured directly
- Anode efficiency:

$$\eta_a = \frac{T^2}{2 \cdot \dot{m}_a \cdot P_d}$$

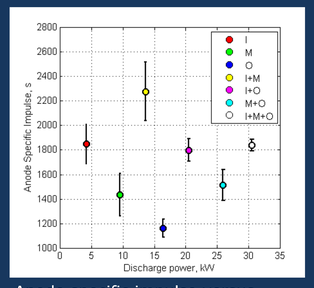
- Anode specific impulse:

$$I_{sp,a} = \frac{T}{\dot{m}_a \cdot g}$$

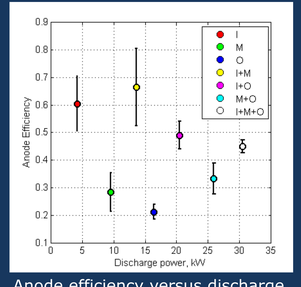
where T is thrust, $\dot{m}_a$ is anode mass flow rate, P_d is the total discharge power, and g is the acceleration due to Earth's gravity.



Thrust versus discharge power



Anode specific impulse versus discharge power



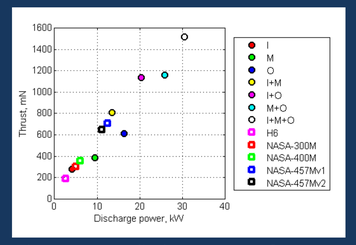
Anode efficiency versus discharge power

At this constant current density, the X3 provided up to 1.5 N of thrust, operated between 22% and 65% anode efficiency, and provided between 1200 s and 2200 s anode specific impulse.

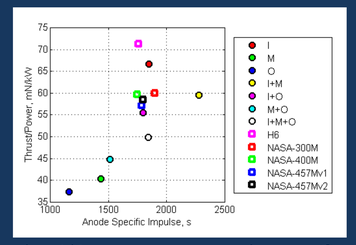
Anode quantities were studied because no attempt was made to optimize cathode or magnetic circuit operation during this experiment.

COMPARISONS TO OTHER STATE-OF-THE-ART HALL THRUSTERS

These test conditions were at sub-nominal current density, and as such, it is necessary to compare the performance to that of other thrusters operating at similarly low current densities. Five high-power, single-channel thrusters were chosen for this comparison: the NASA-300M [6], NASA-400M [7], NASA-457Mv1 [8], NASA-457Mv2 [9], and H6 [10].



Thrust versus discharge power for the X3 and other thrusters



Thrust/Power versus anode specific impulse for the X3 and other thrusters

These plots illustrate that the X3 appears to be operating comparably to these other thrusters except when the larger channels are operating alone.

Future work will explore the reasons for the apparent drop in performance seen in these conditions.

CONCLUSIONS & FUTURE WORK

The X3 has been shown to be operating as expected up to 30 kW, except for some possible low performance with the larger channels operating alone. At 30 kW with all 3 channels operating the thruster produced **1.5 N** of thrust at **1840 s** specific impulse and an efficiency of **45%**.

Significant work is left to be done with the X3:

- Validate the thruster up to 800 V discharge voltage
- Characterize the thruster up to 200 kW discharge power, both with performance metrics and plume diagnostics
- Investigate possible reasons behind low performance seen in M, O, and M+O conditions

ACKNOWLEDGMENTS

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