

Flight MPT Development, Qualification and Thrust Measurement Campaign

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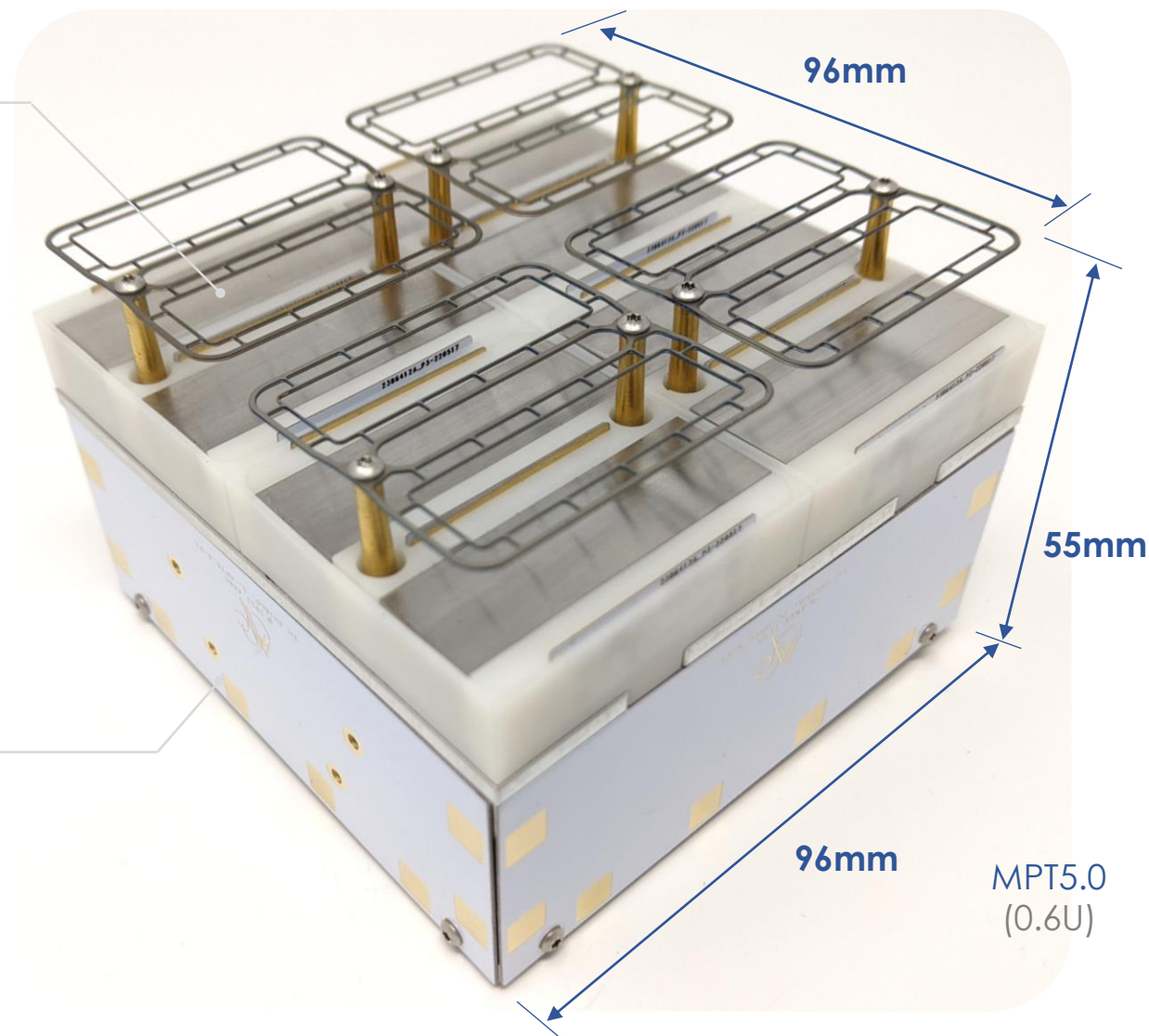
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Xantus Metal Plasma Thruster (MPT)

Technology summary

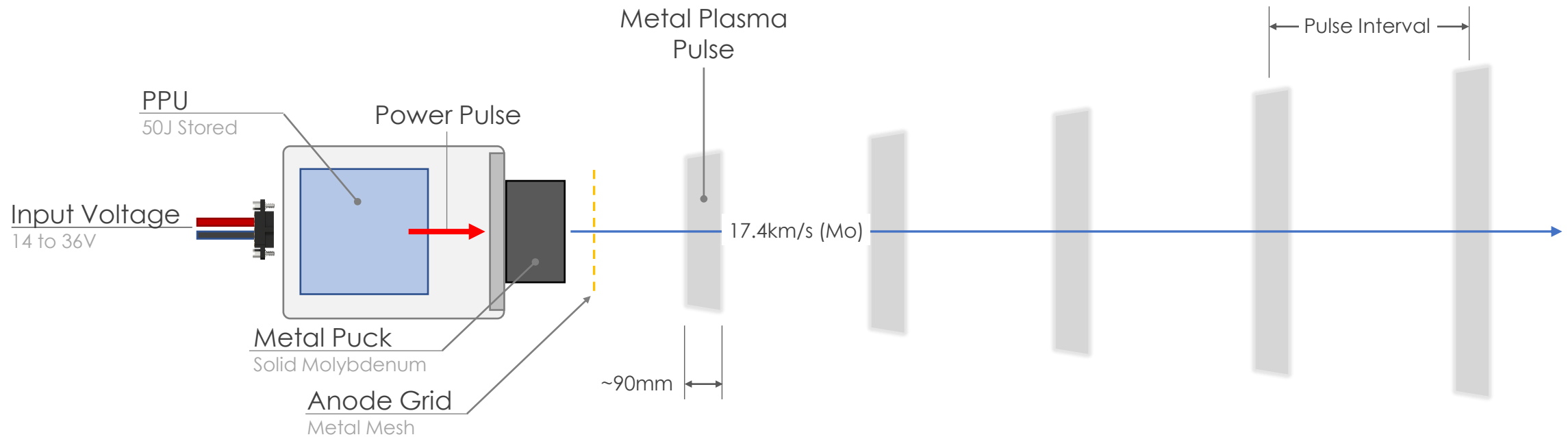
-  **SOLID METAL PROPELLENT**
(Mo, Nb, etc.)
-  **PRECISE IMPULSE CONTROL**
($<0.25\text{mNs}$ impulse bits)
-  **SCALABLE, MODULAR DESIGN**
($\sim 9\text{kNs/U}$ scalable)
-  **END OF LIFE MANEUVERS**
(dormant until needed, turns on instantly)
-  **SIMPLE POWER AND CONTROL UNIT**
(45V capacitor, no high voltage grids)
-  **SHORT LEAD TIME & COMPETITIVE PRICE**
(units built in months)



What is the MPT?

How it works – Xantus

- Each firing of MPT produces a small, repeatable Impulse Bit
- Total Impulse ranging from $\sim 10\mu\text{Ns}$ to several 1000Ns allows for precise attitude and position control as well as orbital maneuvers
- MPT is pulsed, so thrust is rep-rate dependent, $\sim 10\mu\text{N/W}$



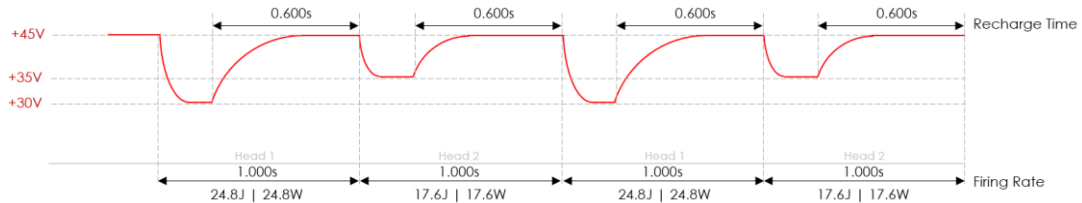
Adaptive Control

Demonstration with Xantus head architecture

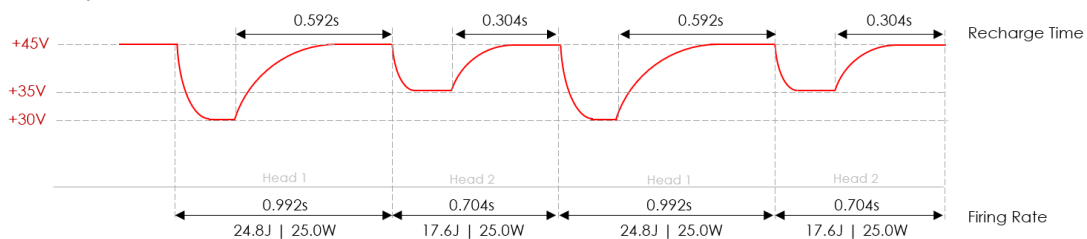
- A simple feedback loop provides adaptive control of the MPT output
- Initial simulations show function
- Implemented and initially tested on High-Power Test Fixture V1

Theory of Operation

Constant Rate Mode

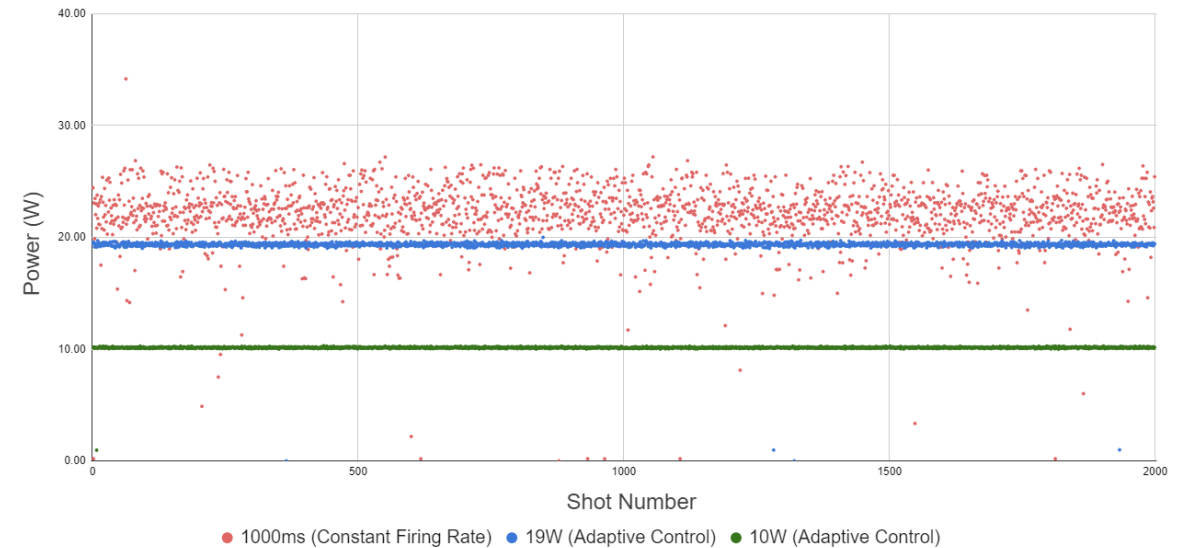


Adaptive Control Mode



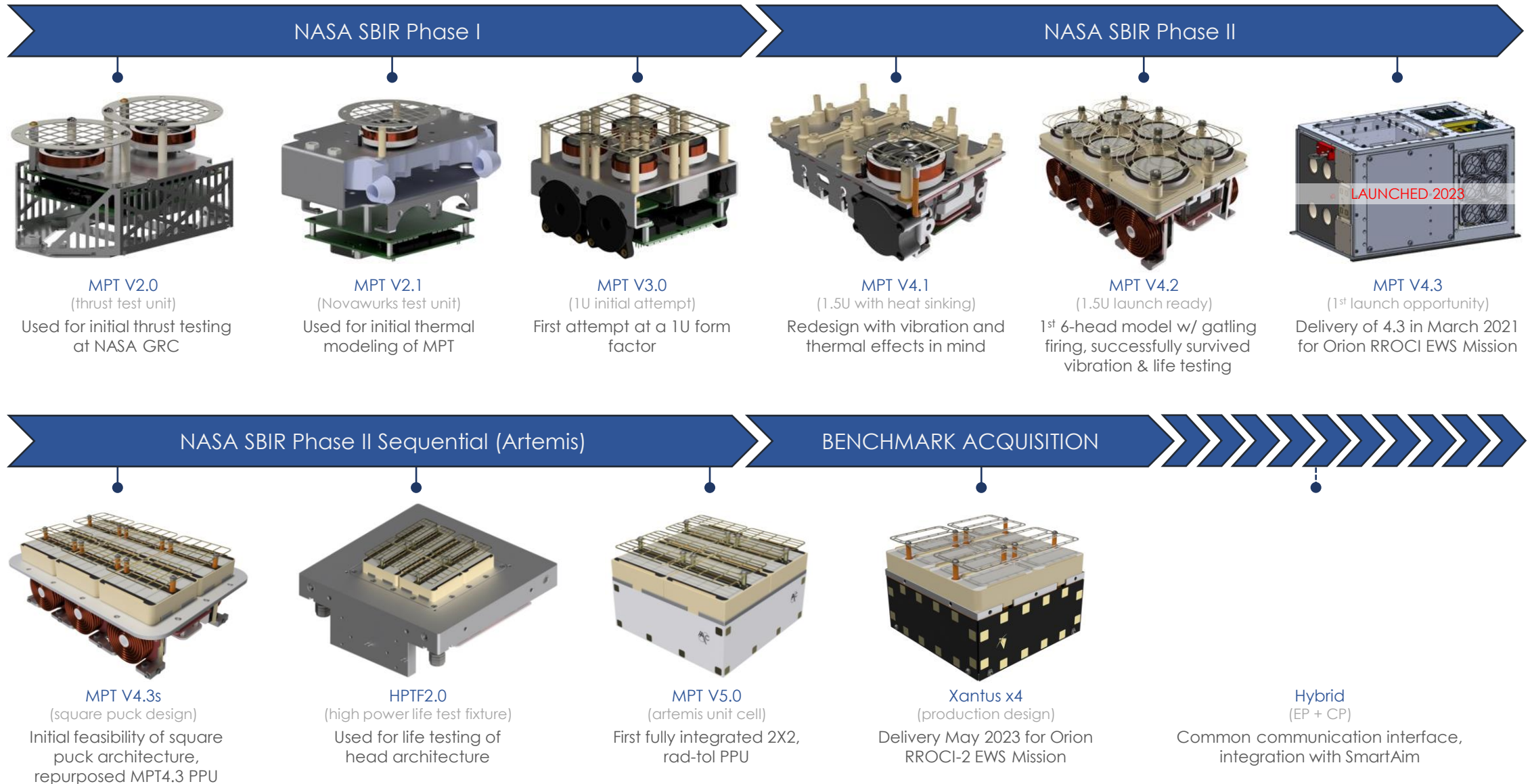
HTPF Run Data Using AC

Shot to Shot Power, Constant Firing Rate vs. Adaptive Control



MPT Timeline

Technology Development Under SBIR (starting in 2018)



MPT Version and Test Summary

From 2021 to Present, totaling >10,000 hrs, >7,000 Ns in vacuum

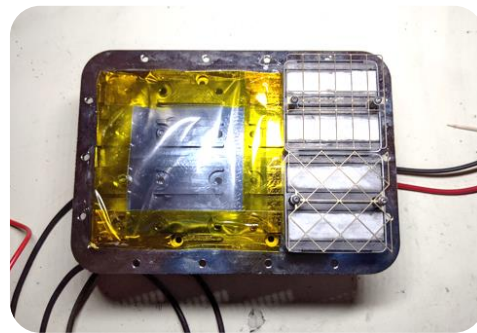
MPT4.3

(RROCI Flight Version)



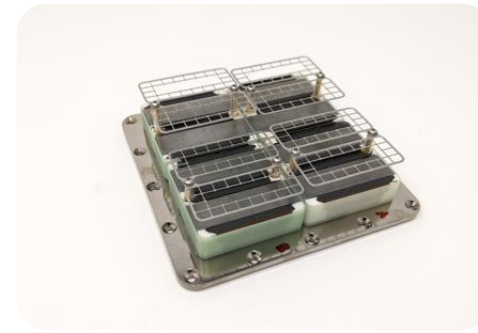
MPT4.3s

(Square Puck Test Bed)



MPT4.3sh

(Xantus Head Design)



MPT5.0

(Xantus Full Assembly)



Head Style

Circular

Square

←

←

Number of Pucks

6 (2x3)

2 (2x1)

4 (2x2)

4 (2x2)

PPU Version

COTS

COTS

N/A

Rad Tol

Units Built, Tested

3

1

3

15

Total Hrs Run

1,100 hr

1,900 hr

4,300 hr

>2,000 hr

Total Pulses Fired

>5.5M*

7.3M

36.2M

8.6M+

Total Impulse Run

960 Ns

760 Ns

4,340 Ns

770 Ns+

Flight Heritage

Almost...

N/A, Test Bed

N/A, Test Bed

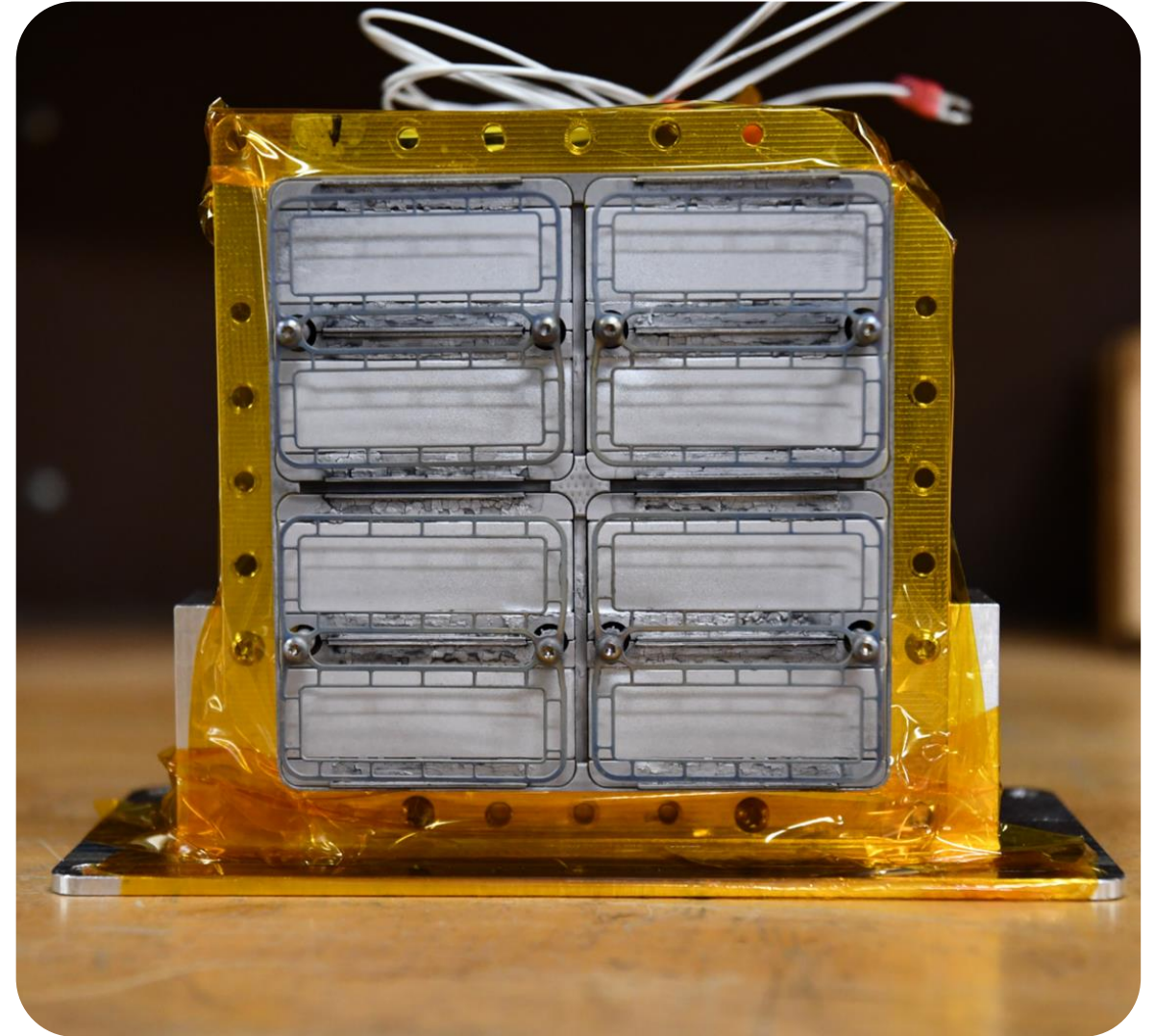
Q1 2024

Unit Tested at NASA Glenn Research Center

Xantus Flight Configuration

Unit tested in both August and November of 2023

- Four Molybdenum Heads
 - Individual Addressable
- Three Firing Methods
 - Single Shot
 - Constant Rate
 - Closed-Loop Adaptive Rate



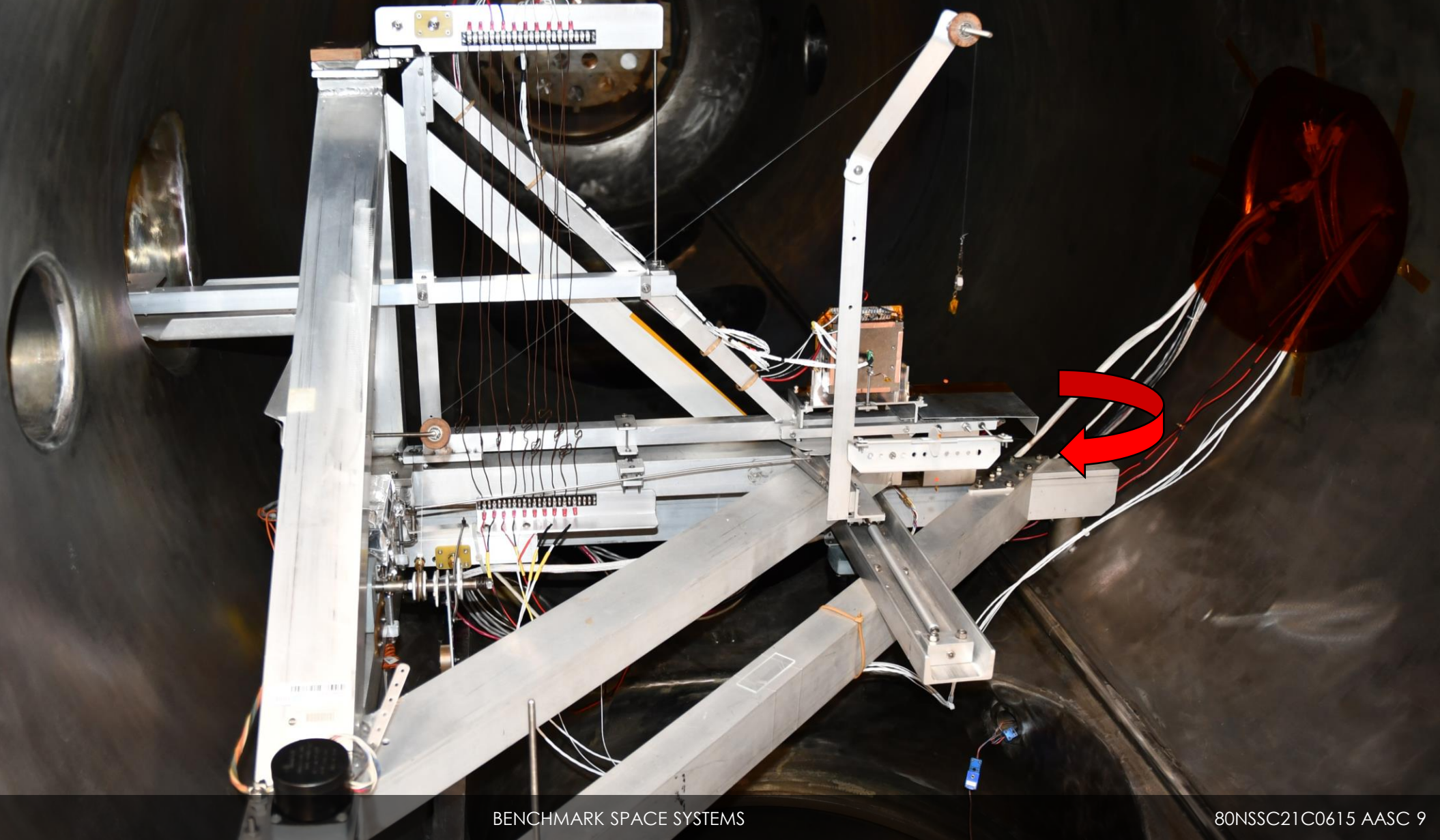
NASA GRC VF-3 Facility

Torsional Thrust Stand



Thrust Stand Operation

Torsional Thrust Stand



Calibration

Deflection and Resonance

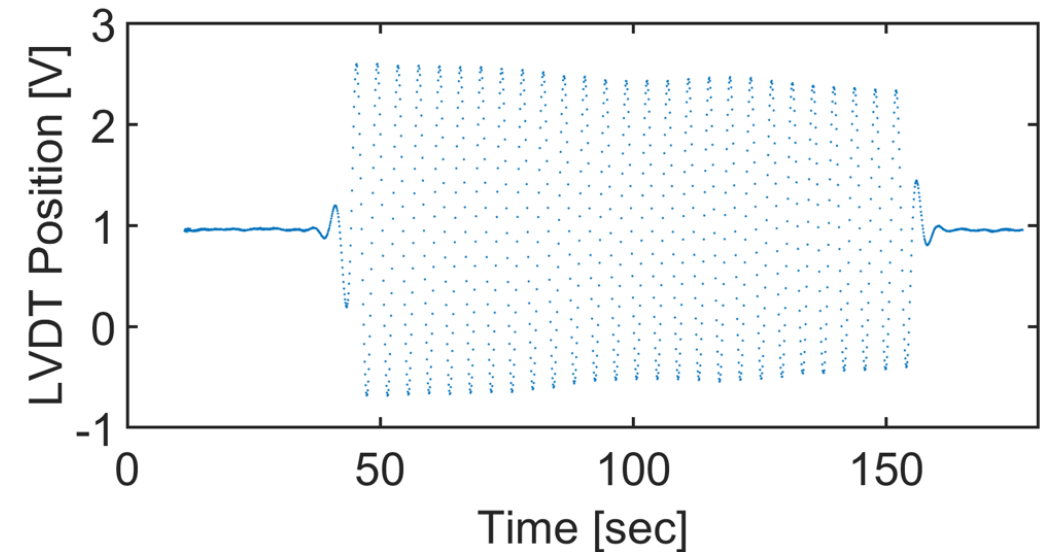
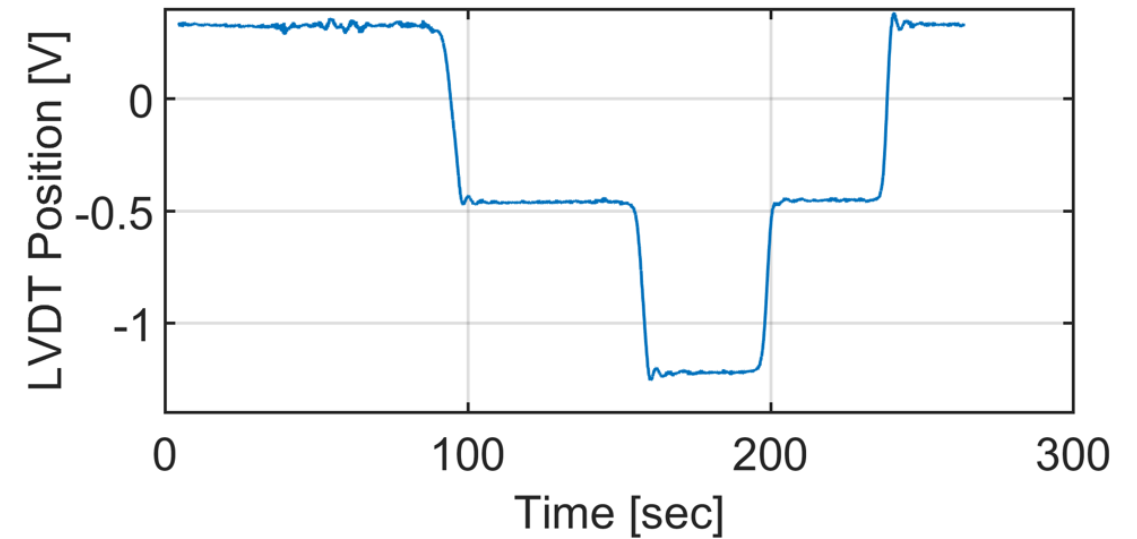
Torsional thrust stand is calibrated two ways

- Deflection

- Stand damped
- Small weights are applied and removed
- Deflection captured and correlated

- Natural Frequency

- Stand undamped
- Deflection introduced, allowed to resonate

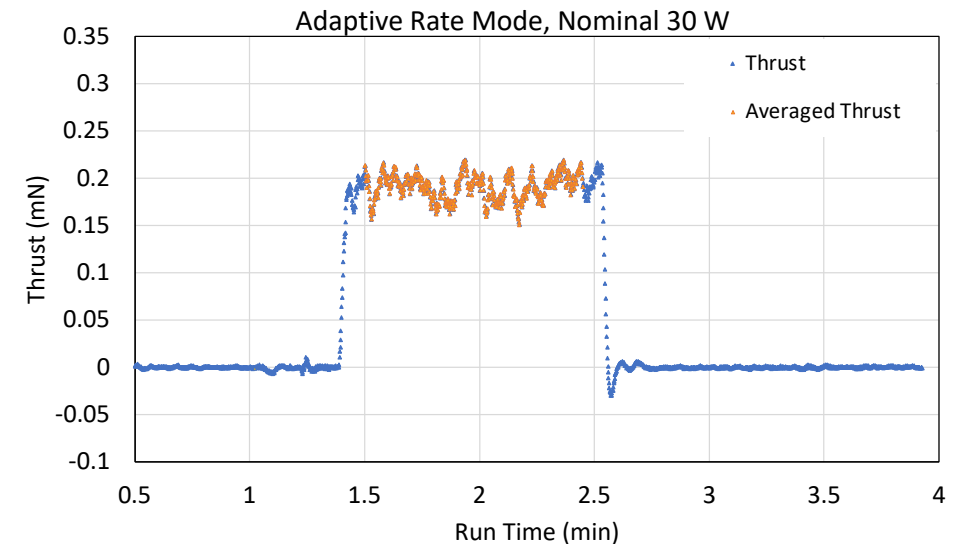
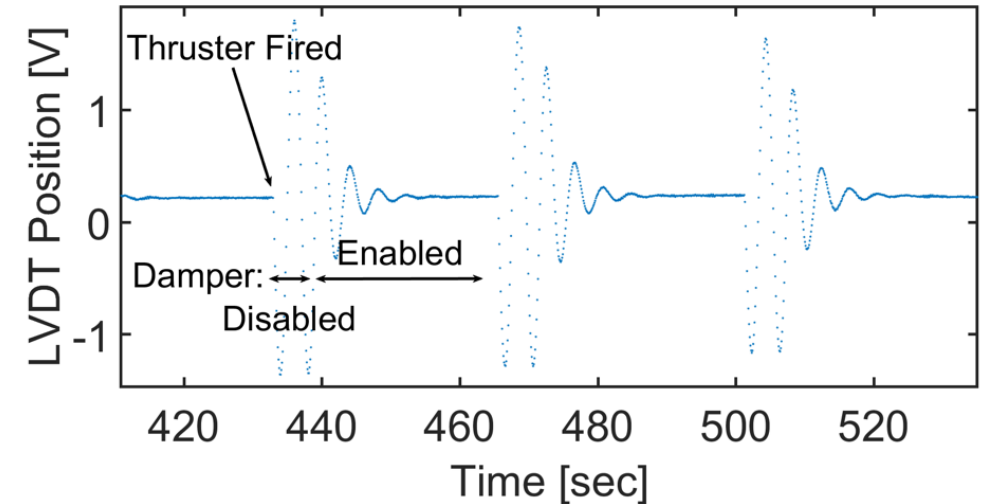


Example Firing

Impulse-Bit and Thrust

Thruster Fired in Two Configurations

- Impulse-Bit
 - Stand undamped
 - Single pulse
 - Creates oscillations in torsional stand
 - Amplitude correlated to Impulse-Bit
- Direct Thrust
 - Stand undamped
 - Thruster fired in adaptive mode
 - Creates consistent deflection in torsional stand
 - Deflection correlated to thrust



Example Dataset

Single-Pulse Firing (August 2023)

Multiple Heads Fired (1,2,3,4)

- Calculated I-Bit
 - Capacitor voltage delta
 - Speed of ejecta
 - Erosion rate
 - Ionization Fraction / Divergence / Transmission
- Measured I-Bit
 - Thrust stand calculation
- Correlation
 - Compare calculated to measured
 - Transmission the most likely delta

Puck	calculated impulse bit, mNs	measured impulse bit, mNs	Impulse bit correction factor	Thrust Efficiency, %	Thrust/Power, mN/kW
1	0.180	0.117	0.65	8.7%	9.9
1	0.122	0.074	0.60	7.7%	8.7
1	0.184	0.121	0.66	8.9%	10.1
1	0.212	0.139	0.66	9.1%	10.4
1	0.209	0.154	0.74	10.2%	11.6
1	0.121	0.089	0.73	9.3%	10.6
1	0.208	0.145	0.70	9.6%	11.0
2	0.144	0.100	0.69	9.0%	10.2
2	0.202	0.158	0.78	10.8%	12.3
3	0.199	0.143	0.72	9.8%	11.2
3	0.170	0.116	0.68	9.1%	10.3
3	0.198	0.147	0.74	10.2%	11.6
3	0.200	0.140	0.70	9.6%	10.9
3	0.207	0.155	0.75	10.4%	11.8
3	0.185	0.142	0.77	10.4%	11.8
4	0.163	0.128	0.78	10.3%	11.8
4	0.193	0.158	0.82	11.2%	12.7
4	0.158	0.127	0.80	10.5%	12.0
4	0.187	0.148	0.79	10.7%	12.2
4	0.173	0.142	0.82	10.9%	12.4
4	0.168	0.132	0.78	10.4%	11.8
4	0.218	0.1650	0.76	10.6%	12.0
4	0.194	0.167	0.86	11.7%	13.4
4	0.205	0.180	0.88	12.1%	13.8
4	0.205	0.182	0.89	12.2%	13.9
4	0.213	0.181	0.85	11.8%	13.4
Speed		1.74E+04	Anode		90%
Thrust Corr.		61.2%	Ion Fraction		85%
Erosion Rate		30	Divergence		80%

Example Firing

Adaptive Firing Mode

Questions?

Backup

NASA GRC VF-3 Tests

Sep. 10-14, 2018 | First 27 shots with a Moly Target: **45V**

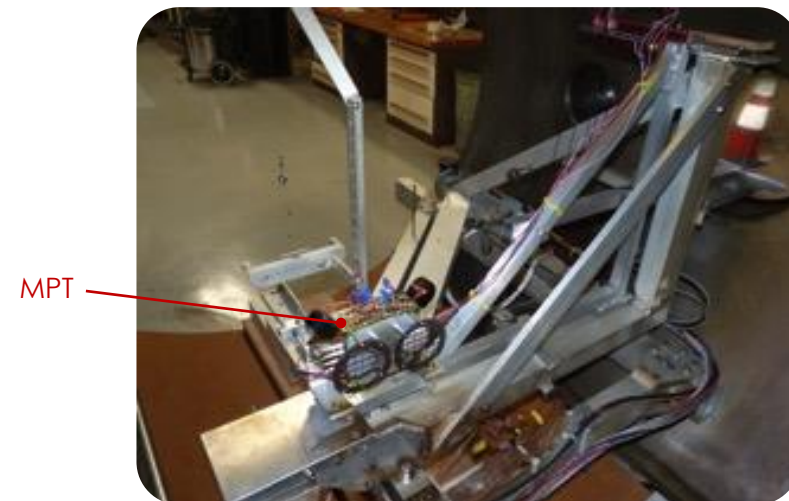
Speed	1.74E+04	Anode	90%
Thrust Corr.	61.2%	Ion Fraction	85%
Erosion Rate	30	Divergence	80%

Shot	Ibit (AASC) (mNs)	Ibit (GRC) (mNs)	AASC/GRC	Eff. (%)	Thrust/P (μ N/W)
1	0.433	0.422	1.03	7.3	8.6
2	0.402	0.353	1.14	6.5	8.4
3	0.390	0.364	1.07	6.8	8.4
4	0.390	0.365	1.07	6.8	8.4
5	0.414	0.444	0.93	7.9	8.5
...					
25	0.433	0.445	0.97	7.7	8.6
26	0.402	0.376	1.07	6.9	8.4
27	0.411	0.459	0.90	8.2	8.5
Average	0.411	0.407	1.01	7.3	8.5
STDEV	0.020	0.043	0.074	0.006	0.079
STDEV %	4.8%	10.5%	7.3%	7.6%	0.9%

- Shot-shot spread in I-bit is remarkably low (5%)
- For reference, a total I-bit (27 shots) of 11 mNs would impart a DV of 0.56 mm/s to a 20 kg bird!

*These tests were conducted under the sponsorship of NASA's Small Satellite Technology Program and performed at NASA GRC by the Electric Propulsion Systems Branch.

- AASC I-bits were calculated from the measured charge/shot and the corrections for anode/plume/macros
- Average calculated I-bit agrees with the average measured I-bit, using the right corrections
- 1- σ spread in calculated I-bit is better than that measured, because the measured values do not know, apriori, where on the target the plume originates (the lever arm varies)



Spacecraft Contamination Concern

Backscatter is not a problem by design

- MPT plasma flows away from thruster face (spacecraft) and is collisionless after 10mm (no backwards diffusion)
- Limited backscatter (from anode) is captured by splashguard
- No electrostatic fields as with other EP technologies
- Contamination is not a problem for the emitting spacecraft
- Could nearby spacecraft (in a cluster) be contaminated?
 - Estimates show that for separation >10km, even one monolayer of metal film would require >30 years

