



Monoprop-Electrospray Propulsion (MEPS)

Lunar Missions Enabled by Chemical-Electrospray Propulsion
Technology Expo

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Cooperative Agreement (CA) Partnerships with
Universities and NASA Centers

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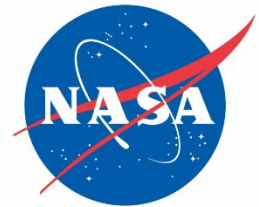
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Monoprop-Electrospray Multimode Propulsion

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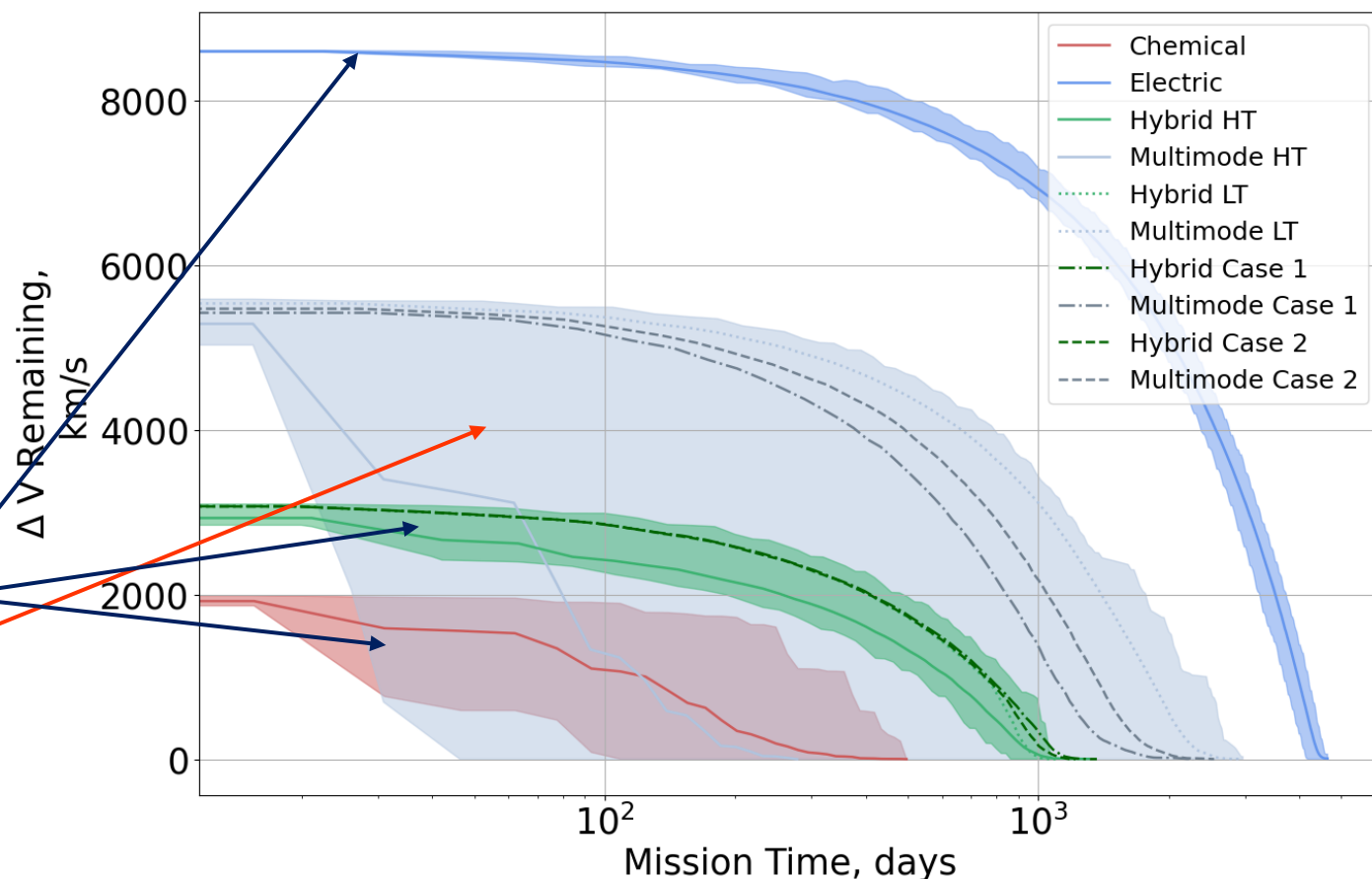


Potential Impact - Benefits

- Enables S/C mission flexibility/adaptability
- Enables new missions only possible w/ both CP and EP
- Provides S/C mass savings, especially for small/CubeSats

Mission capability space (shaded regions) for GEO servicing scenarios

- Narrow capability space
 - EP, CP, hybrid
- Wide capability space
 - Multimode
 - Can be all CP, or all EP, or some combo
 - Even determined post-launch



Monoprop-Electrospray Multimode Propulsion

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- **Enables new missions only possible w/ both CP and EP**
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- NASA Smallsat Lunar Mission Scenarios
 - Multimode S/C provide flexibility
 - Can do all-CP mission, all-EP mission or anywhere in between
 - Mission enabled by, only possible with multimode – need EP for spiral into orbit, CP to maintain orbit against lunar gravity perturbations

Propulsion	Time of Flight (days)	Propellant Used (kg)	Delivered Mass (kg)	Total Impulse (kNs)
Case 1	IMAP Rideshare to 100 km circular polar			
Chemical (4x ECAPS HPGP 1N)	133.3	9.40	14.60	21.21
Electric (BIT-3)	596.1	1.82	22.18	46.42
Multimode (4x MEPS)	273.4	6.27	17.73	29.28
Case 2	IMAP Rideshare to 6500 km circular polar			
Chemical (4x ECAPS HPGP 1N)	133.5	3.80	20.20	8.52
Electric (BIT-3)	291.7	0.68	23.32	17.46
Multimode (4x MEPS)	198.3	2.53	21.47	14.65
Case 3	Direct lunar transfer to 100 km circular polar			
Chemical (4x ECAPS HPGP 1N)	4.78	8.73	15.26	19.71
Electric (BIT-3)	Not feasible due to Earth gravitational perturbations.			
Multimode (4x MEPS)	77.56	8.55	15.45	26.05
Case 5	IMAP Rideshare to NRHO			
Chemical (4x ECAPS HPGP 1N)	94.14	0.46	23.54	1.033
Electric (BIT-3)	178.46	0.072	23.93	1.83
Multimode (4x MEPS)	158.98	0.32	23.68	0.57

Monoprop-Electrospray Multimode Propulsion

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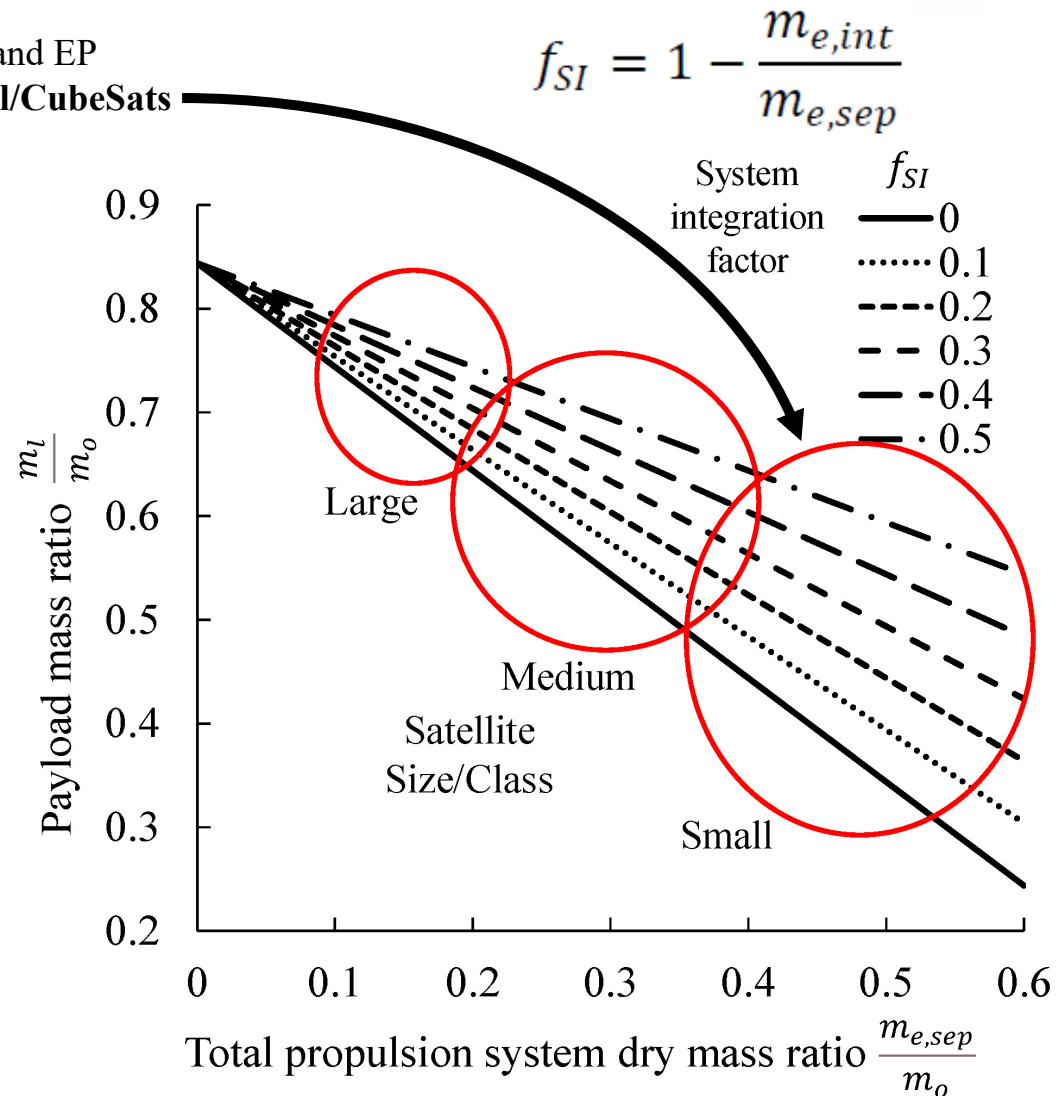


Potential Impact - Benefits

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- Enables new missions only possible w/ both CP and EP
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- Smallsats, with large dry propulsion system mass, benefit the most when CP and EP share mass (high integration factor)

$$\frac{m_l}{m_o} = e^{-(\Delta V / I_{sp, dm} g_o)} - \frac{m_{e, sep}}{m_o} (1 - f_{SI})$$



Monoprop-Electrospray Multimode Propulsion

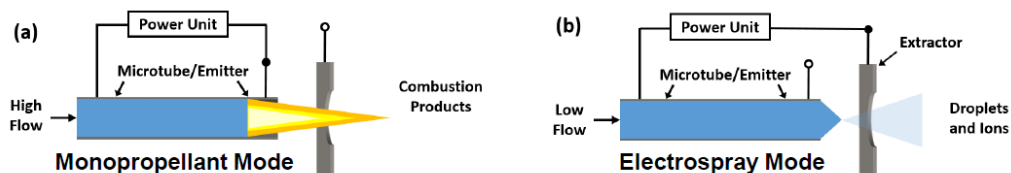
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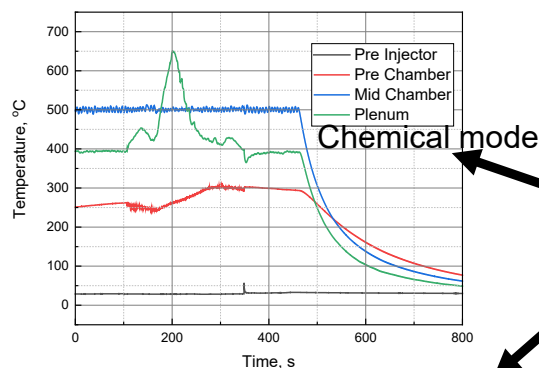
Technology Overview

- Integrated chemical and electric propulsion into a single propulsion package: one thruster using one propellant
- Switchable between high-thrust (1N, 180s) catalytic decomposition, high-specific impulse (0.5mN, 1000s) electrospray modes

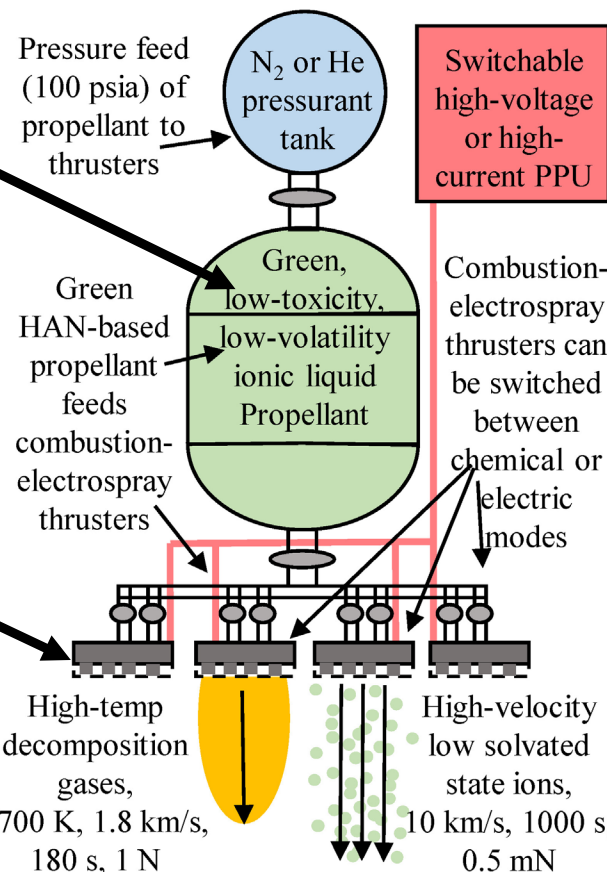
Integrated Monopropellant-Electrospray Thruster Concept



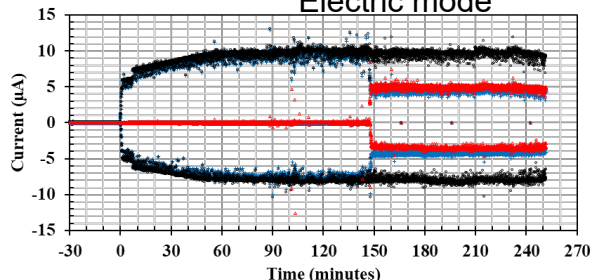
Demonstrated stable catalytic decomposition of 0.1 mN thrusters with Pt catalyst at 250C preheat



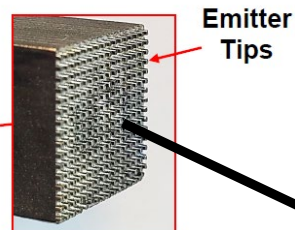
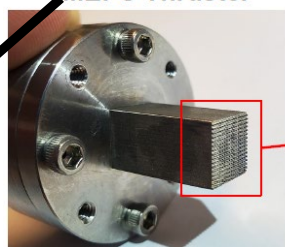
Repeated synthesis of specially designed green FAM110A propellant.



FAM-110A at 2.8 nL/s per emitter; $\pm 3,250$ V Electric mode



MEPS Thruster



Demonstrated stable electrospray in both positive and negative polarities with active feed system (± 3250 V onset voltage)

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PPU & Feed System

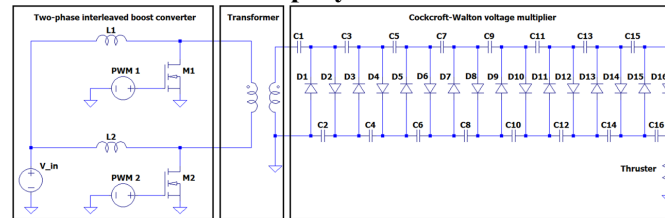
Benchtop Power Processing Unit

- Separate PPU for each mode with opportunities for integration
- Modifiable duty cycle offers voltage control in both modes
- Chemical mode: boost converter for heater power
- Electrospray mode: interleaved boost converter, step-up transformer, capacitor diode multiplier

Benchtop Feed System

- Blow-down with separate flow paths for each mode
- Operates at a single pressure
- Chemical mode: large ID tubing with vernier valve
- Electrospray mode: small ID tubing with two pressure reducing orifices and vernier valve

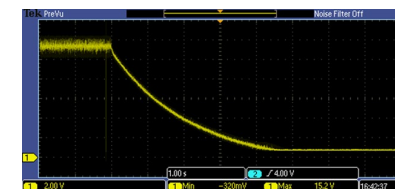
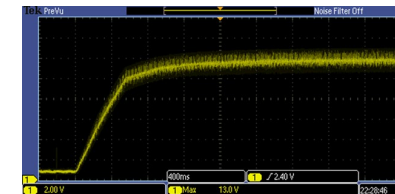
Electrospray PPU Structure



Full Array Voltage & Power Requirements

Mode	Voltage	Power
Chemical	12 V	10 W
Electrospray	3250 V	1.3 W

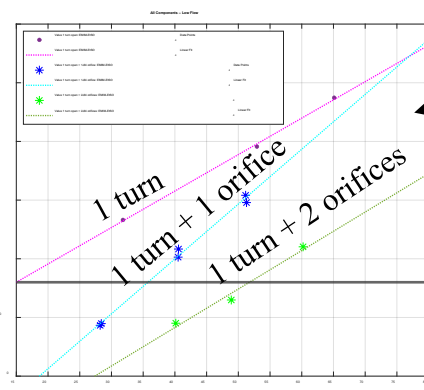
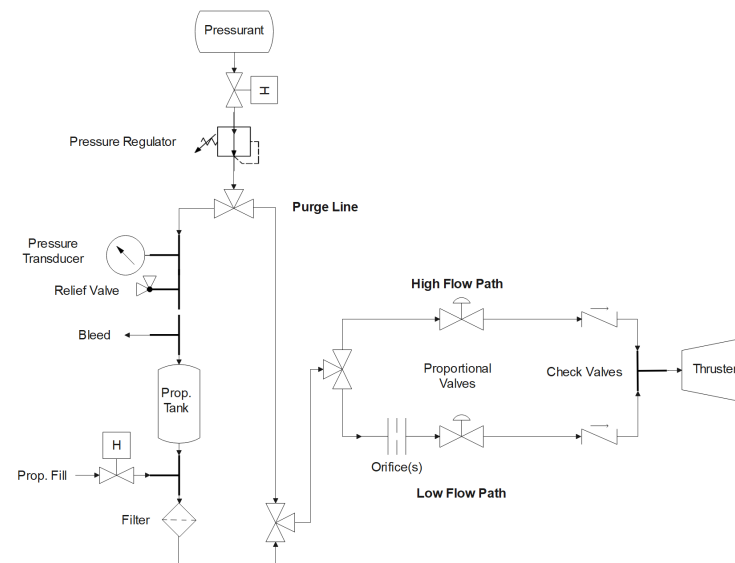
Electrospray PPU Turn-On and Turn-Off Waveforms



Flow rate as function of pressure for electrospray mode for various system configurations

Full Array Flow Rate Requirements

Mode	Flow Rate
Chemical	$\approx 100 \mu\text{L/s}$
Electrospray	$\approx 700\text{-}850 \text{ nL/s}$



Monoprop-Electrospray Multimode Propulsion

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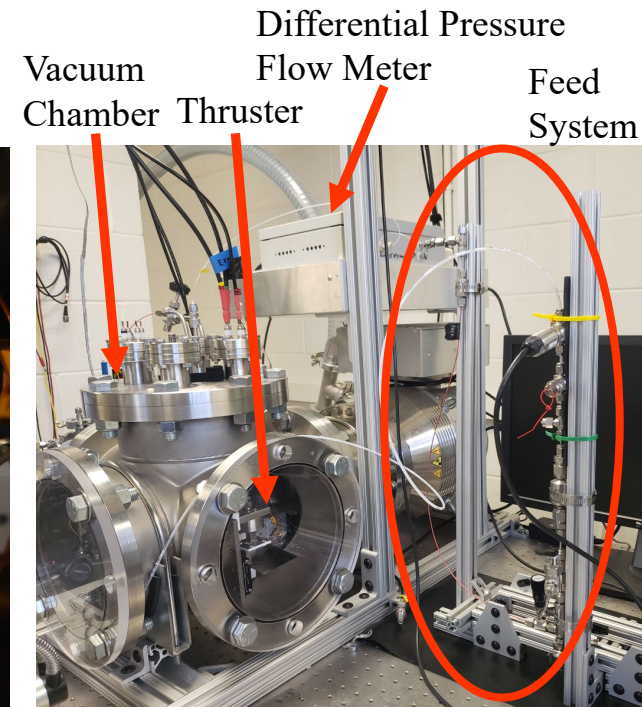
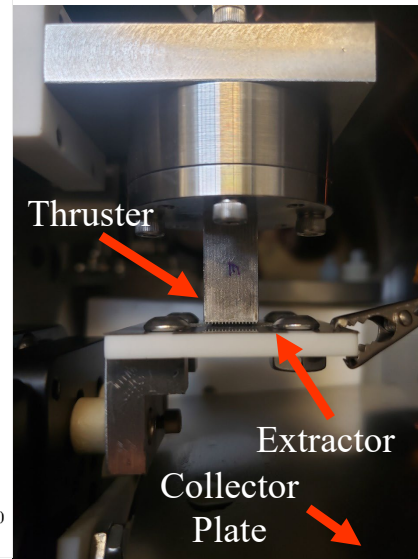
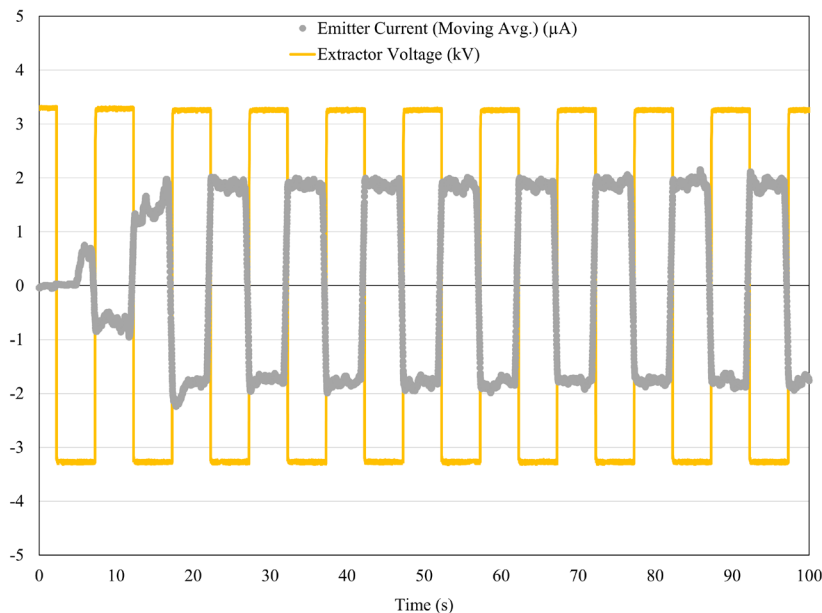
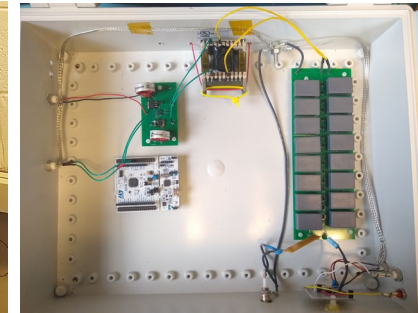
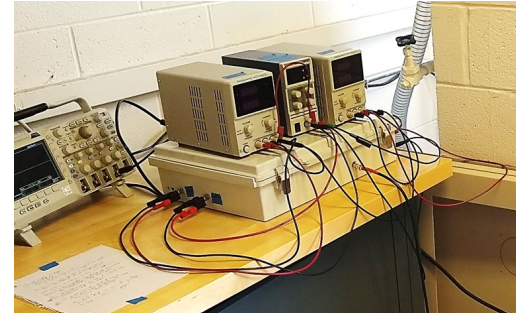


Risk Reduction Integrated Test

- First integrated test with benchtop feed system and PPU
- Subscale test: 6 emitters
- **Emim-EtSO₄** used as propellant simulant
- Feed system: orifices replaced with PEEK tubing to minimize clogging
- PPU: delivered positive voltage only (did not provide the negative voltage for mode-switching)
- **Results:**
 - Demonstrated stable electrospray from 5 emitters
 - Flow meter did not produce data ($\sim 15\text{-}50\text{nL/s}$)
 - Test terminated due to time constraints, all systems functional at conclusion



PPU



Monoprop-Electrospray Multimode Propulsion

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	Key Performance Parameter (KPP)	State-of-the-art	Hybrid (CP + EP)	Monoprop-Electrospray
Thruster	Modes of Operation	1	1	2
	Thrust (mN)	1000 CP, 0.5 EP	1000 CP, 0.5 EP	1000 CP, 0.5 EP
	Isp (sec)	200 (AF-M315E), 1200 EP	200 (AF-M315E), 1200 EP	180 CP, 1000 EP
	CP Density-Isp (kg-s/m ³)	300,000 (AF-M315E)	300,000 (AF-M315E)	270,000 (FAM110A)
	Efficiency (%)			15
	Power (W)			10 (CP), 16 (EP)
	Dry Mass (kg)			0.2
PPU	Mass (kg)			0.5
Feedsys	Mass (kg)			1.3
System for Lunar Ref. Mission (1200m/s CP + 800m/s EP, 12U 25kg)	System Dry Mass (kg)	1.5 CP, 1.4 EP	1.5 CP, 1.4 EP (2.9 together)	2.0 together
	System Integration Factor	0	0	0.31 > 0.27
	Propellant Mass (kg)	16.0 CP, 3.9 EP	11.4 CP, 0.9 EP (12.3total)	12.3 CP, 1.0 EP (13.3total)
	Wet Propulsion (kg)	17.5 CP, 5.3 EP	15.2	15.3
	System Volume (m ³)	0.012 CP, 0.004 EP		
	System Volume (U)	12 CP, 4 EP	11.2	10.4
	Impulse per Volume (N-s/U)	2,630 CP, 9,520 EP	2,830	3,330
Capability Space (same Lunar propulsion package)	Burntime (hrs/days)	1.1hrs CP, 113days EP	0.8hrs CP, 25.8days EP	0.9hrs CP, 28.7days EP
	Impulse per Volume (N-s/U)	2,630 CP, 9,520 EP	1,060	320 to 12,800
	Total Burn Time	1.1hrs CP, 113days EP	25.8 days	0.9hrs to 385days
	25kg S/C Delta-V (km/s)	2.0 CP, 2.0 EP	1.7 to 2.0	1.3 to 7.4

Slightly lower performance

But

Same mass, smaller volume, higher impulse

And

Flexibility, wide range of mission capability in one propulsion package

A Propulsion Package with a wide range of mission capability space and Lunar, OTV, and Deep-space potential

20x larger delta-V range

Wide range of total impulse capability

Questions?