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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Monoprop-Electrospray Multimode Propulsion

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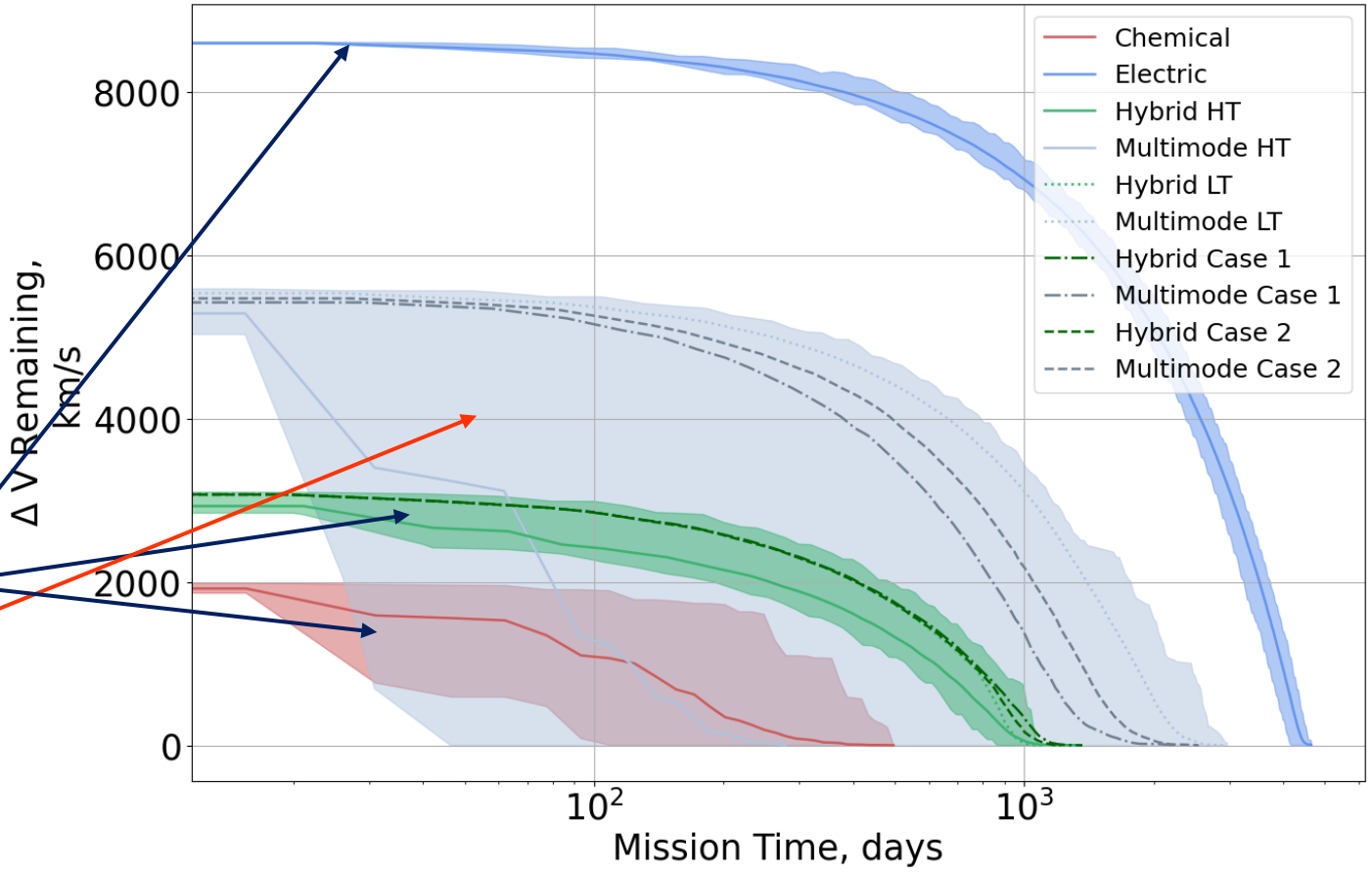
Potential Impact - Benefits

- **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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- NASA Smallsat Lunar Mission Scenarios
  - Multimode S/C provide flexilibity
    - 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

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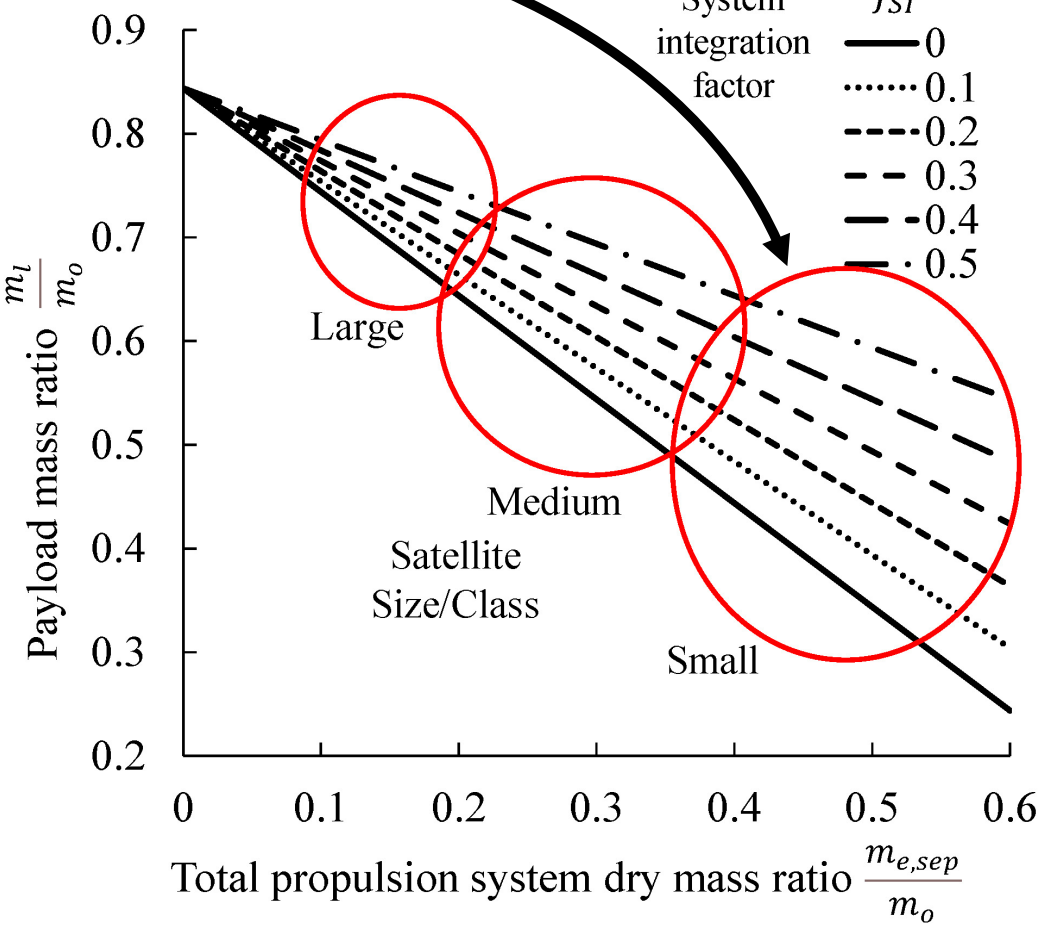
- **Provides S/C mass savings, especially for small/CubeSats**

- Smallsats, with large dry propulsion system mass, benefit the most when CP and EP share mass (high integration factor)

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

$$f_{SI} = 1 - \frac{m_{e,int}}{m_{e,sep}}$$



Monoprop-Electrospray Multimode Propulsion

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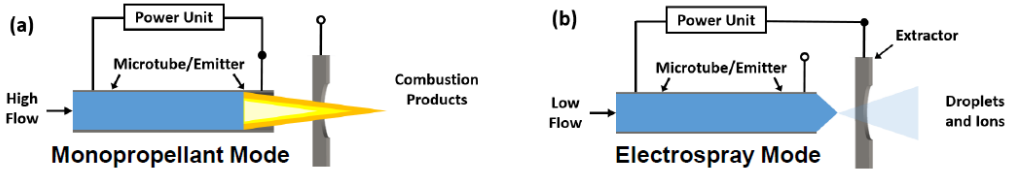
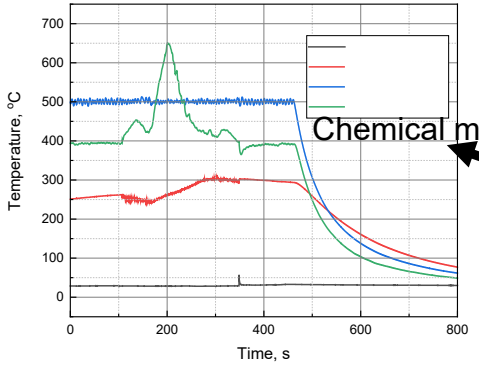
Technology Overview

- Integrated chemical and electric propulsion into a single propulsion package: one thruster using one propellant
- Switchable between high-thrust (**1N, 180s**) catalytic decombustion, 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.

Pressure feed (100 psia) of propellant to thrusters

N_2 or He pressurant tank

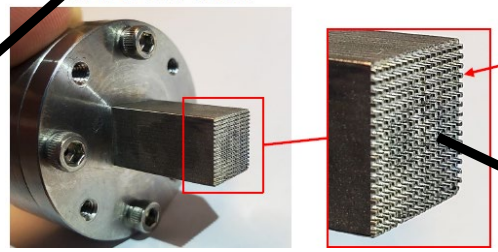
Switchable high-voltage or high-current PPU

Green, low-toxicity, low-volatility ionic liquid Propellant

Green HAN-based propellant feeds combustion-electrospray thrusters

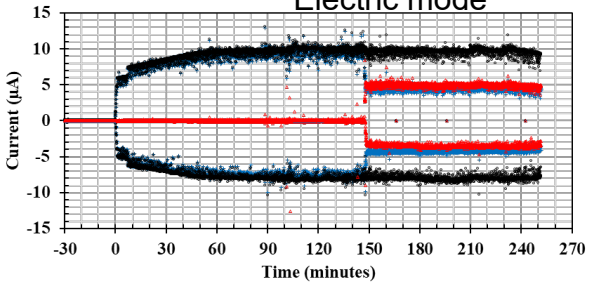
Combustion-electrospray thrusters can be switched between chemical or electric modes

MEPS Thruster



FAM-110A at 2.8 nL/s per emitter; ±3,250 V

Electric mode



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

High-temp decomposition gases, 1700 K, 1.8 km/s, 180 s, 1 N

High-velocity low solvated state ions, 10 km/s, 1000 s, 0.5 mN

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PPU & Feed System

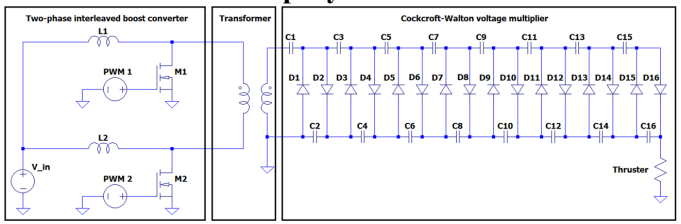
Benchtop Power Processing Unit

- Separate PPUs 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

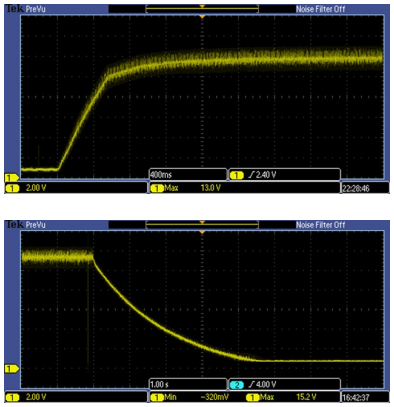
Benchtop Feed System

- 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

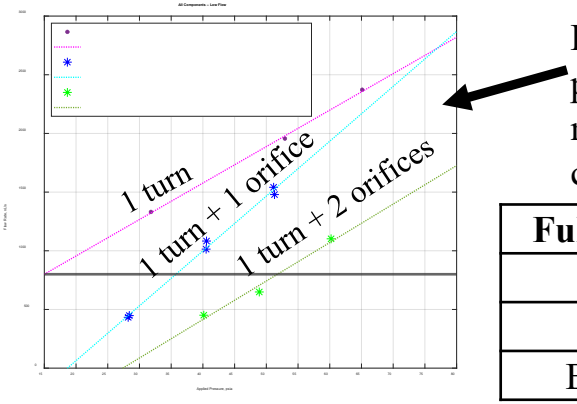
Electrospray PPU Structure



Electrospray PPU Turn-On and Turn-Off Waveforms

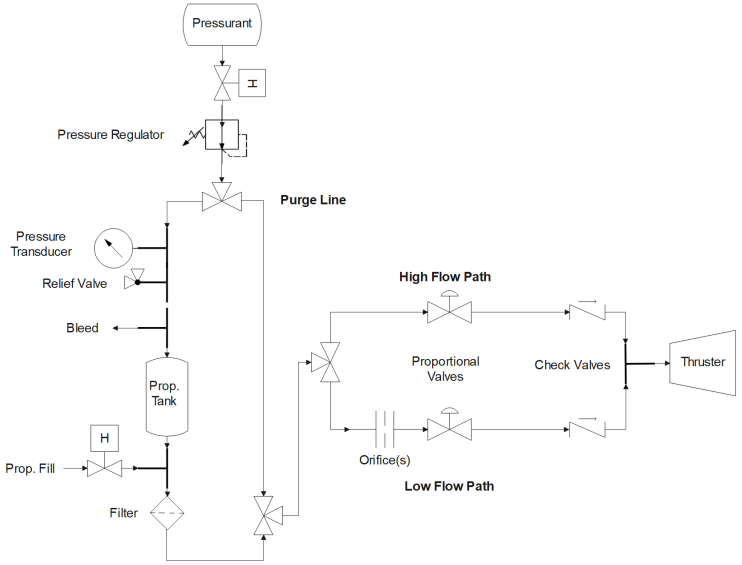


Full Array Voltage & Power Requirements		
Mode	**Voltage**	**Power**
Chemical	12 V	**10 W**
Electrospray	3250 V	**1.3 W**



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

Full Array Flow Rate Requirements	
Mode	**Flow Rate**
Chemical	≈100 μL/s
Electrospray	≈700-850 nL/s



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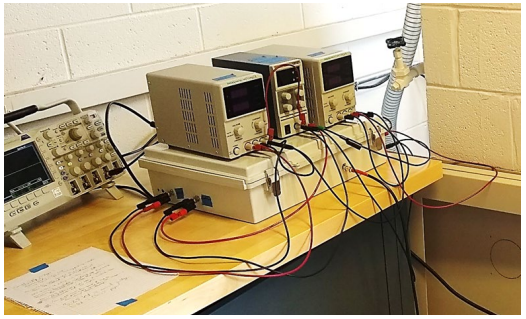
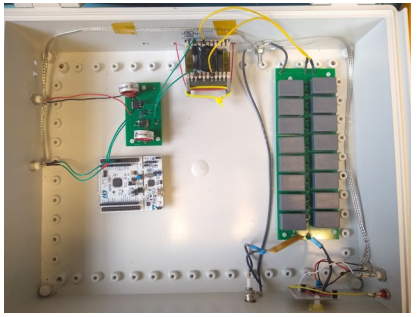
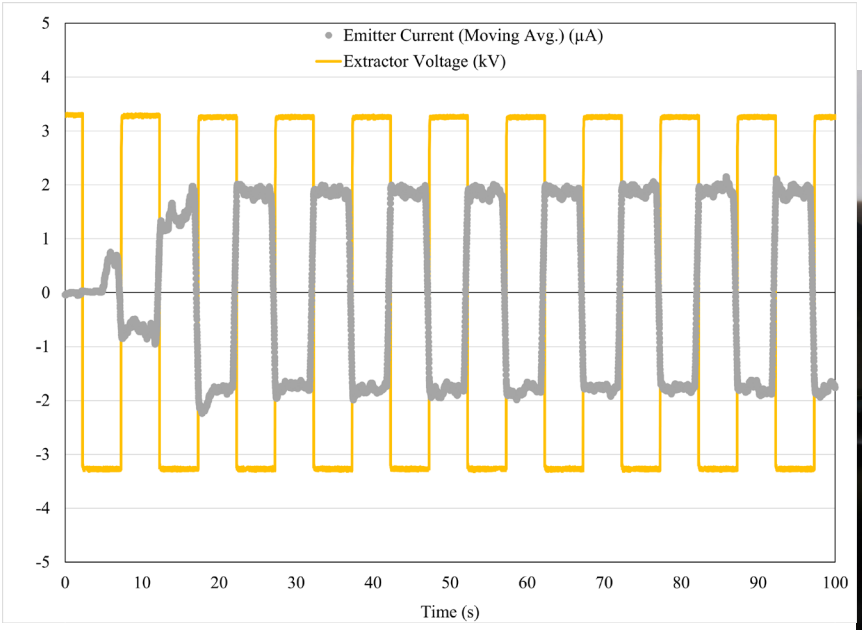
Risk Reduction Integrated Test

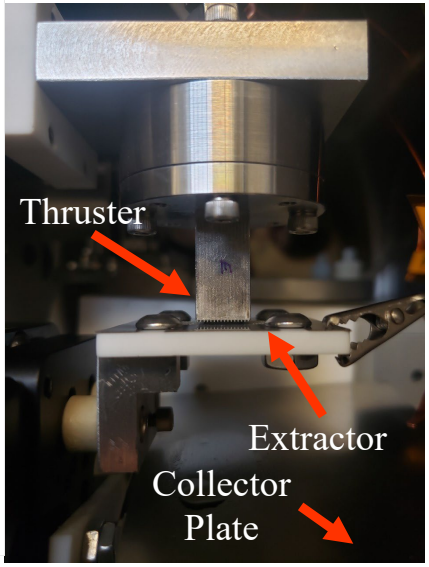
- First integrated test with benchtop feed system and PPU
- Subscale test: 6 emitters
- **Emim-EtSO$_4$** used as propellant simulant
- Feed system: orifices replaced with PEEK tubing to minimize clogging
- PPU: delivered positive voltage only (did not provide the negative voltage for mode-switching)
- **Results:**
  - Demonstrated stable electrospray from 5 emitters
  - Flow meter did not produce data (~15-50nL/s)
  - Test terminated due to time constraints, all systems functional at conclusion

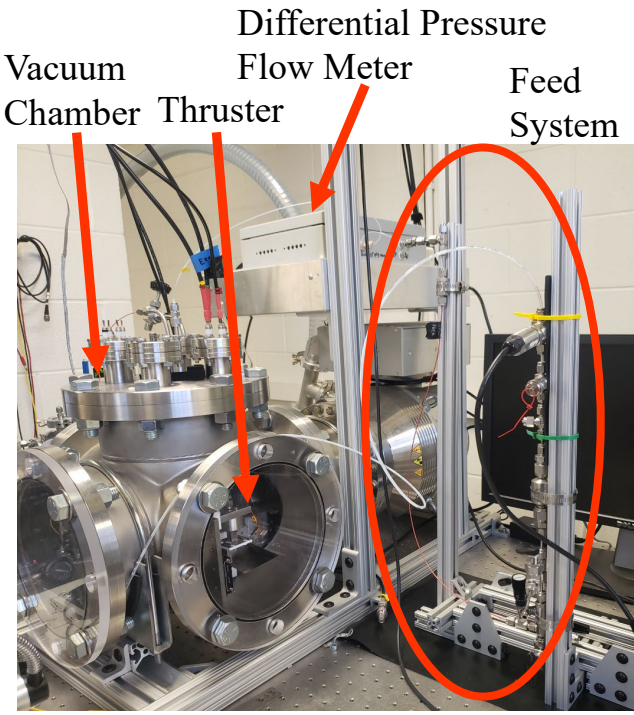


PPU









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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
	Burntime (hrs/days)	1.1hrs CP, 113days EP	0.8hrs CP, 25.8days EP	0.9hrs CP, 28.7days EP
Capability Space (same Lunar propulsion package)	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?