AASC's MPT* Propulsion for CubeSats:

2021 CubeSat Workshop

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[Contributions from Katherine Velas & Simon Leemans: 2016-2017]

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AASC's Metal Plasma Thruster (MPT)

Talk highlights

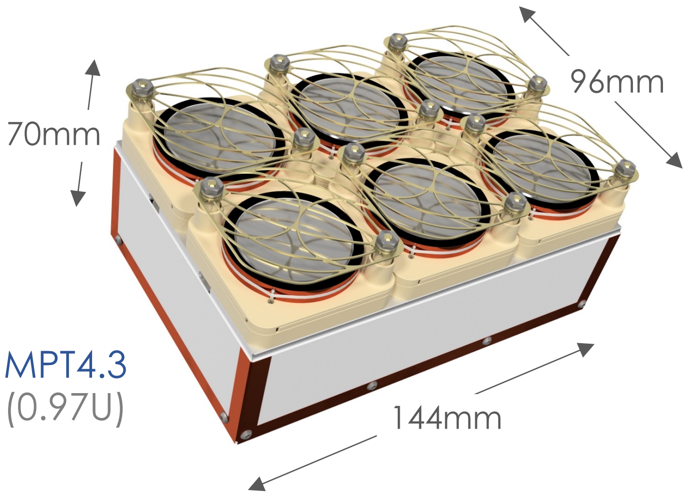
- This talk presents an evaluation by mission analysis, of four thruster options for CubeSats
  - Mission 1: Provide ~100m/s ΔV to a 12U/20kg CubeSat in LEO for orbit change and drag compensation
  - Mission 2: Provide 1000m/s ΔV to a 12U/22kg CubeSat for Lunar orbit insertion

- Analysis proceeds as follows:
  - Establish Operating Points for various thrusters
  - Estimate Key Parameters: Wet Mass/Volume and Mission Capability of thrusters

- Assess Pros and Cons of different candidates

AASC's Metal Plasma Thruster (MPT)

Technology summary



SOLID METAL PROPELLENT
(Mo, Nb, etc.)

PRECISE IMPULSE CONTROL
(<0.25mNs impulse bits)

SCALABLE, MODULAR DESIGN
(~6000Ns/U scalable)

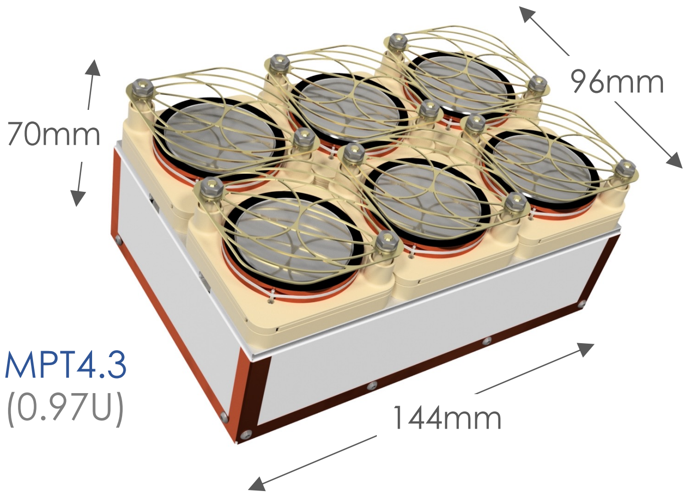
SIMPLE POWER AND CONTROL UNIT
(40V capacitor, no high voltage grids)

END OF LIFE MANEUVERS ← Zero Standby Power
(dormant until needed, turns on instantly)

SHORT LEAD TIME & COMPETITIVE PRICE

AASC's Metal Plasma Thruster (MPT)

Publications & Flight Opportunity

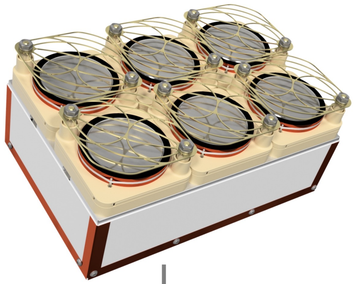


- AIAA Journal of Propulsion and Power
  - Metal Plasma Thruster for Small Satellites, Mahadevan Krishnan, Katherine Velas and Simon Leemans, https://doi.org/10.2514/1.B37603
  - Journal of Propulsion and Power: Impulse Bit Measurements from Metal Plasma Thruster, Mahadevan Krishnan, John Frankovich and Jonathan A. Mackey https://doi.org/10.2514/1.B38191
- AASC was selected by ASTRA LLC to deliver an MPT for ASTRA's EWS Rapid Revisit Optical Cloud Imager (RROCI) Mission (U.S. Space Force), launch in early 2022
- MPT will:
  - Raise 12U from 780km up to 830km (~25 days)
  - Drag it down to burn up at end of mission

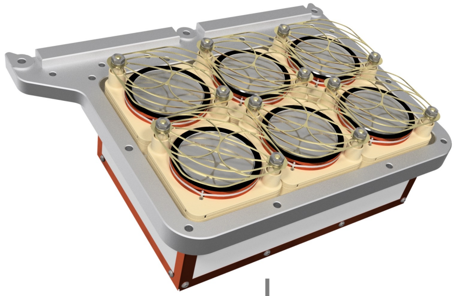
AASC's Metal Plasma Thruster (MPT)

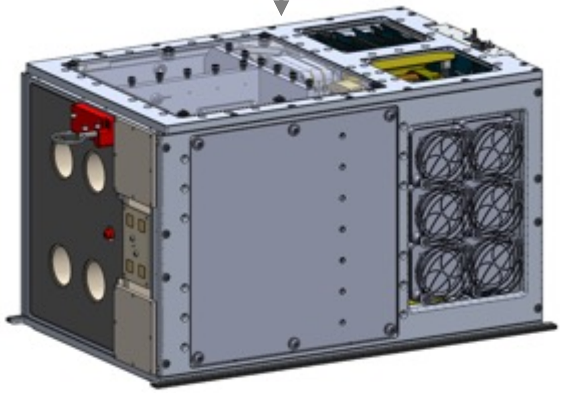
Supernova flight ready MPT4.3 (TRL 6)

- Vibration/Shock tests completed (twice);
- Thrust measured at NASA/GRC VF-3 Facility (twice)
- A Flight-Ready Unit has been delivered to Pumpkin for integration into the ASTRA LLC 12U CubeSat (US Space Force RROCI Mission/February 2022)

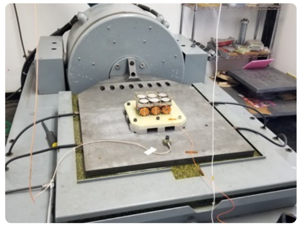


AASC Vacuum testing Chamber
>40M pulses accumulated over four years

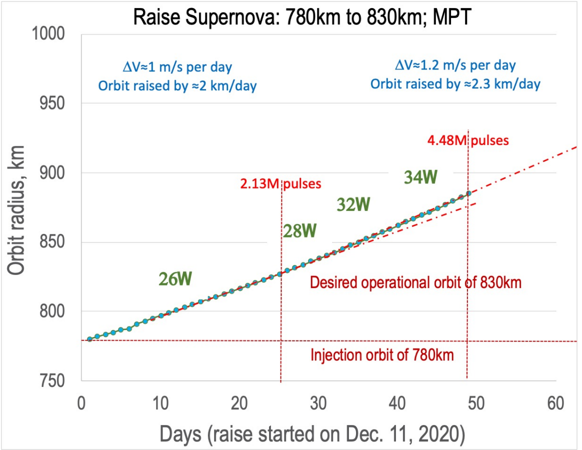




Supernova CubeSat integration
(launch scheduled for early 2022)



"SHAKE" tests at QTS/Huntington Beach, CA
9.6g rms and sine sweep

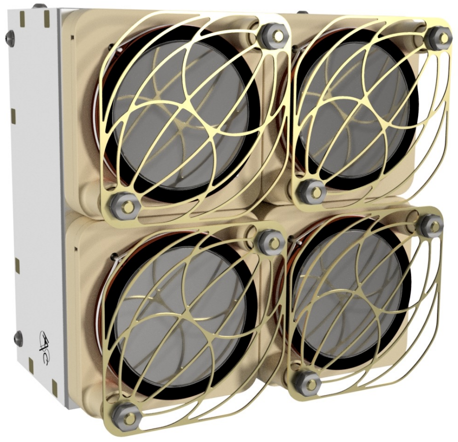


ORBIT RAISE SIMULATION IN VACUUM
(50-day continuous burn)

Emerging Electric Propulsion Options for CubeSats

Selection of candidates

AASC MPT



~6000Ns/U

~12µN/W

Zero standby power

No neutralizer required

ENPULSION IFM Nano

~6000Ns/U

~10µN/W

Variable ISP

Heater to melt Indium

Requires neutralizer

ThrustMe NPT30-12

1.5U

~3300Ns/U

~11µN/W

~1000s ISP

Heater to vaporize Iodine

Requires neutralizer

ACCION TILE3

~800Ns/U

~22µN/W

Variable ISP

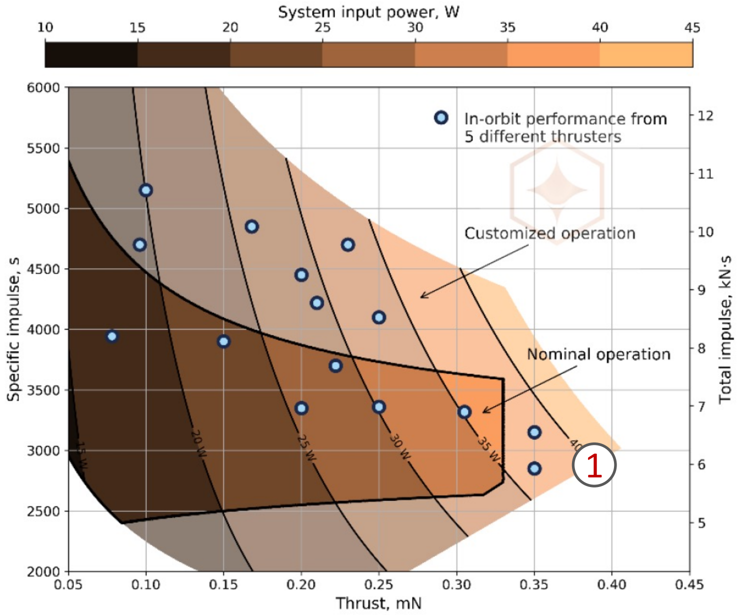
Requires neutralizer

These candidates are all modular and scalable for 10kg - 100kg Satellites

ENPULSION Field Emission Electric Propulsion (FEEP)

Indium Solid Propellant | 40W Operation Point

DYNAMIC THRUST RANGE	10 TO 350 µN	
NOMINAL THRUST	330 µN	
SPECIFIC IMPULSE	2,000 TO 6,000 s	
PROPELLANT MASS	220 g ± 5%	
TOTAL IMPULSE	> 5,000 Ns	
POWER AT NOMINAL THRUST	40 W INCL. NEUTRALIZER	
OUTSIDE DIMENSIONS	100.0* x 100.0* x 82.5 mm	3
MASS (DRY / WET)	680 / 900 g	2
TOTAL SYSTEM POWER	8 – 40 W	
HOT STANDBY POWER	3.5 W	
COMMAND INTERFACE	RS422/RS485	
TEMPERATURE ENVELOPE (NON-OPERATIONAL)	-40 TO 105°C	
TEMPERATURE ENVELOPE (OPERATIONAL)	-20 TO 40 °C	
SUPPLY VOLTAGE	12 V, 28 V, OTHER VOLTAGES UPON REQUEST	



IFM NANO

1	POWER	40 W
	THRUST	390 µN
	ISP	2800 s
	SPEED	27.5 km/s
	TOTAL IMPULSE	6000 Ns
	ΔMASS: FUEL	362 g
	M-ION	1.92E-25 kg
	V (ACC.)	453 V
	I / P (BEAM)	11.8 mA / 5.36 W
	THRUST EFFICIENCY	13.4%
	T/P RATIO	9.8 µN/W

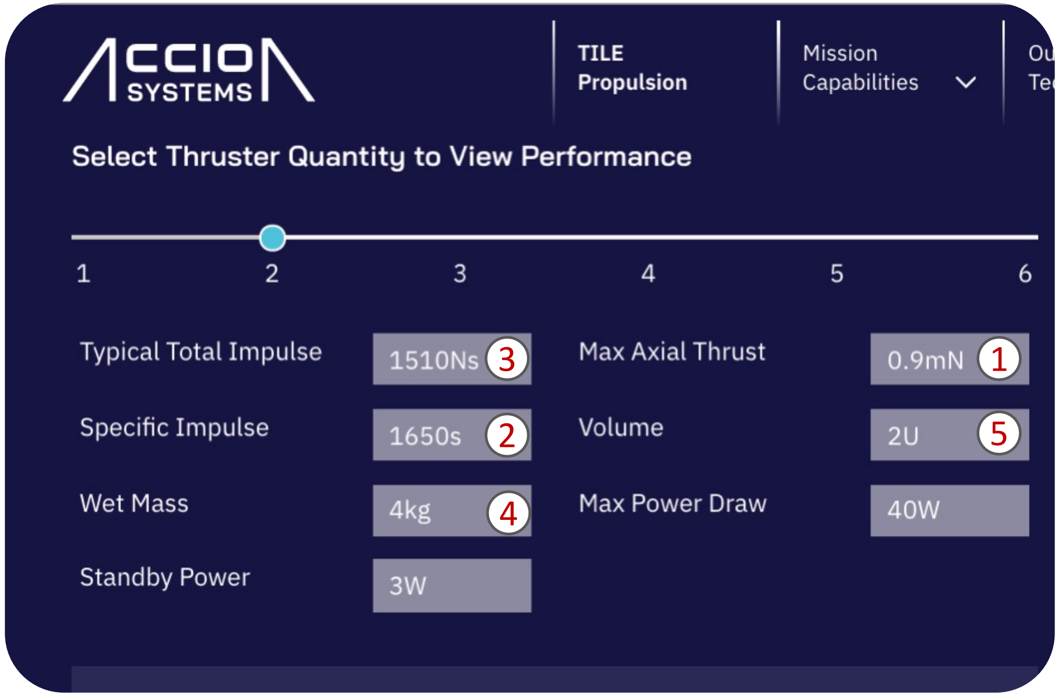
IFM NANO (1-UNIT)

	POWER	40 W
2	DRY MASS	0.67 kg
	WET MASS	1.03 kg
3	VOLUME	0.83 U
	ΔV TOTAL	300 m/s
	ΔV ORBIT LOWER	70 m/s
	ΔV RESIDUAL	230 m/s

- This FEEP has flight heritage and is suited to 3U – 16U CubeSats

ACCION Electrospray Field Emission Electric Propulsion (FEEP)

Ionic Liquid Propellant | 40W Operation Point



TILE3

	POWER	40 W
①	**THRUST**	900 μN
②	**ISP**	1650 s
	SPEED	16.2 km/s
③	**TOTAL IMPULSE**	1510 Ns
	ΔMASS: FUEL	143 g
	MOL. WEIGHT	2.2E-24 (72.5c/g)
	V (ACC.)	1822 V
	I / P (BEAM)	4.0 mA / 7.28 W
	THRUST EFFICIENCY	18.2%
	T/P RATIO	22.5 μN/W

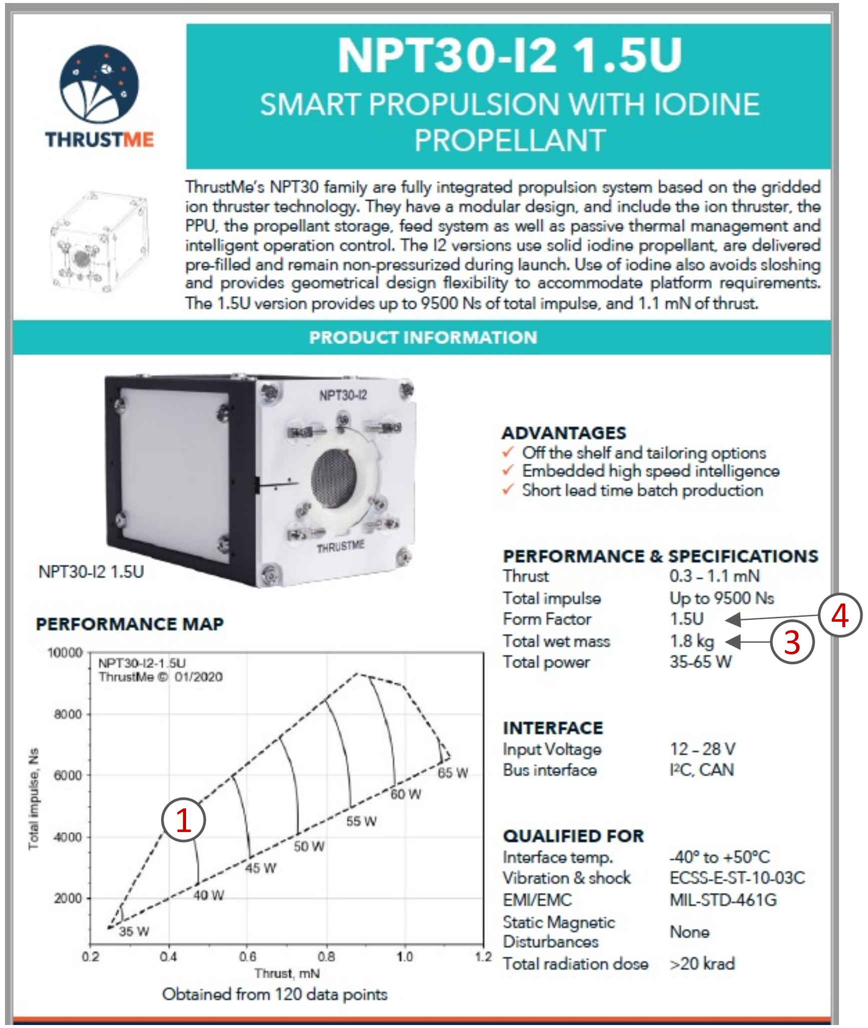
TILE3 (1-UNIT)

	POWER	40 W
	DRY MASS	3.86 kg
④	**WET MASS**	4.00 kg
⑤	**VOLUME**	2.00 U
	ΔV TOTAL	76 m/s
	ΔV ORBIT LOWER	70 m/s
	ΔV RESIDUAL	6 m/s

- This FEEP should fly in 2021, is modular and highly scalable

ThrustMe Iodine Ion Propulsion

Iodine Solid Propellant | 40W Operating Point



NPT30-I2 1.5U

SMART PROPULSION WITH IODINE PROPELLANT

THRUSTME

ThrustMe's NPT30 family are fully integrated propulsion system based on the gridded ion thruster technology. They have a modular design, and include the ion thruster, the PPU, the propellant storage, feed system as well as passive thermal management and intelligent operation control. The I2 versions use solid iodine propellant, are delivered pre-filled and remain non-pressurized during launch. Use of iodine also avoids sloshing and provides geometrical design flexibility to accommodate platform requirements. The 1.5U version provides up to 9500 Ns of total impulse, and 1.1 mN of thrust.

PRODUCT INFORMATION

NPT30-I2 1.5U

ADVANTAGES

- ✓ Off the shelf and tailoring options
- ✓ Embedded high speed intelligence
- ✓ Short lead time batch production

PERFORMANCE & SPECIFICATIONS

Thrust	0.3 – 1.1 mN
Total impulse	Up to 9500 Ns
Form Factor	1.5U (4)
Total wet mass	1.8 kg (3)
Total power	35-65 W

INTERFACE

Input Voltage	12 – 28 V
Bus interface	I²C, CAN

QUALIFIED FOR

Interface temp.	-40° to +50°C
Vibration & shock	ECSS-E-ST-10-03C
EMI/EMC	MIL-STD-461G
Static Magnetic Disturbances	None
Total radiation dose	>20 krad

PERFORMANCE MAP

Obtained from 120 data points

NPT 30-12, 1.5U

(1)	POWER	40 W
	THRUST	450 μN
(2)	ISP	1000 s
	SPEED	9.81 km/s
	TOTAL IMPULSE	5000 Ns
	ΔMASS: FUEL	839 g
	MOL. WEIGHT	2.11E-25 kg
	V (ACC.)	63.4 V
	I / P (BEAM)	34.8 mA / 2.21 W
	THRUST EFFICIENCY	5.5%
	T/P RATIO	11.3 μN/W

NPT 30-12, 1.5U (1-UNIT)

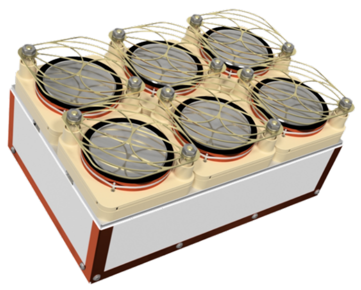
	POWER	50 W
	DRY MASS	1.00 kg
(3)	WET MASS	1.84 kg
(4)	VOLUME	1.5 U
	ΔV TOTAL	271 m/s
	ΔV ORBIT LOWER	70 m/s
	ΔV RESIDUAL	201 m/s

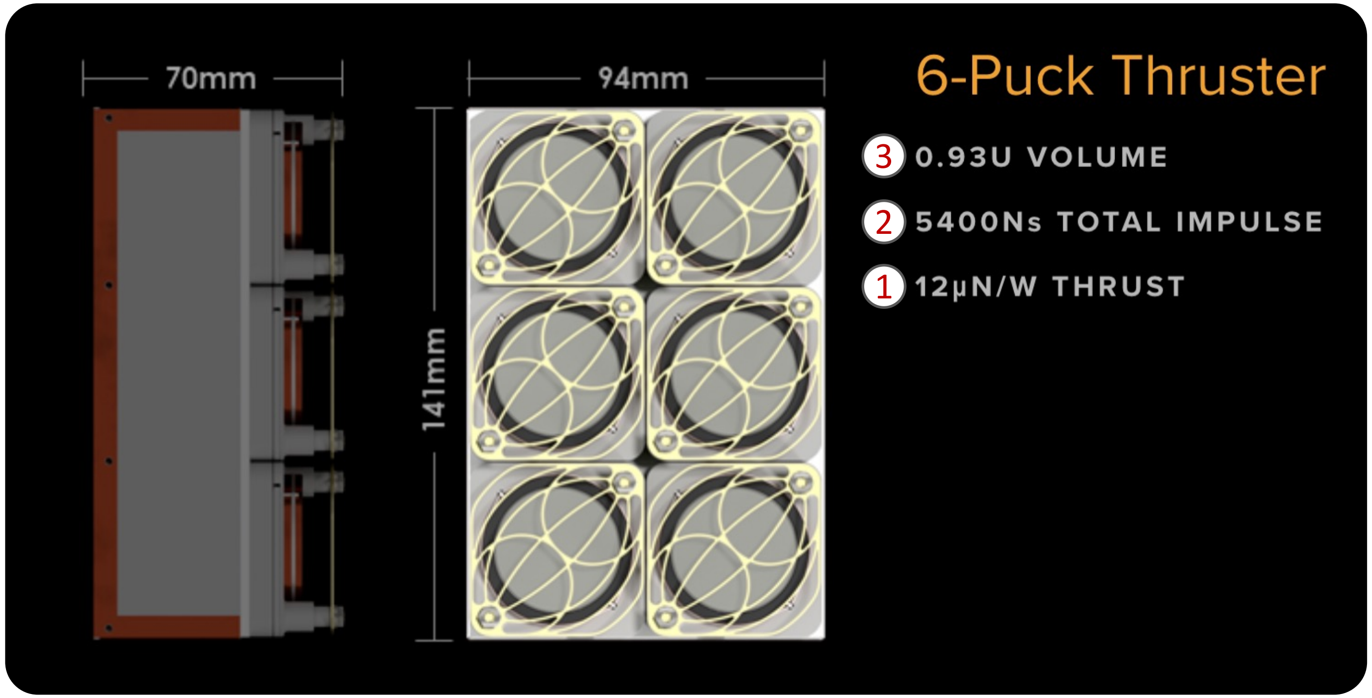
- This Ion Engine should fly in 2021, is modular and scalable

(2) Javier Martínez Martínez, Dmytro Rafalskyi and Ane Aanesland; **Development and Testing of the NPT30-I2 Iodine Ion Thruster, IEPC-2019-811** *September 15-20, 2019*

AASC Metal Plasma Thruster

Molybdenum Solid Propellant | 40W Operating Point





	MPT (AASC)	
	POWER	40 W
1	THRUST	482 µN
	ISP	1774 s
	SPEED	17.4 km/s
2	TOTAL IMPULSE	5400 Ns
	ΔMASS: FUEL	474 g
	ΔQ	0.264 C
	ΔM	8.71E-9 kg
	M_dot	4.30E-8 kg/s
	THRUST EFFICIENCY	10.5%
	T/P RATIO	12.0 µN/W

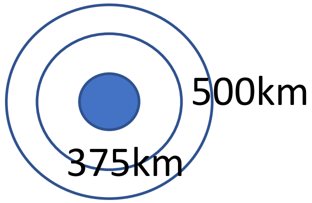
	MPT (1-UNIT)	
	POWER	40 W
	DRY MASS	1.20 kg
	WET MASS	1.67 kg
3	VOLUME	0.93 U
	ΔV TOTAL	249 m/s
	ΔV ORBIT LOWER	70 m/s
	ΔV RESIDUAL	179 m/s

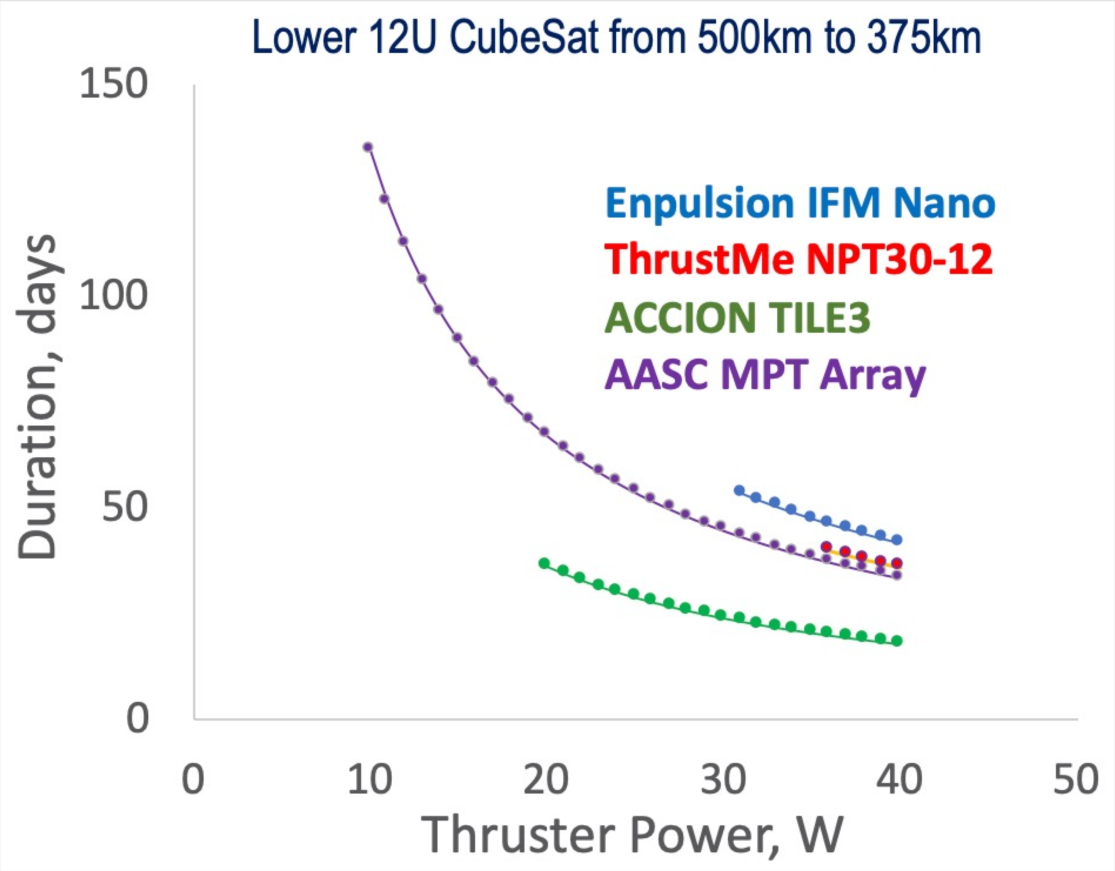
- This Thruster should fly in early 2022, is modular and scalable

Mission 1: Part 1

Lower a 12U CubeSat from 500km (injection) to 375km (operation)

- Mission duration v. input power for different candidates





- Power range taken from nominal performance maps of IFM Nano and ThrustMe literature

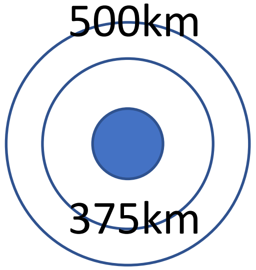
- AASC MPT requires *ZERO standby power*, so may be operated over the widest range of input power (<1W to 100W): useful for power limited mission phases

Thruster	Dry Mass, kg	Wet Mass, kg	Volume, U
Enpulsion IFM Nano	0.670	1.032	0.83
AASC MPT 4.3	1.200	1.674	0.93
ThrustMe NPT 30-12 1.5U	1.000	1.839	1.50
ACCION TILE3	3.857	4.000	2.00

- IFM Nano offers lowest wet mass/volume for such a mission
- MPT is a close second, but offers wider operating power range, *requiring zero standby power*

Mission 1: Part 2

Drag Compensation at 375km



- Residual ΔV after orbit insertion provides drag compensation
- Three of the four candidates provide drag compensation in VLEO for ~250 days; ACCION TILE3 (TWO units) does not provide much drag compensation, but ……..

IFM NANO (Enpulsion)

DRAG (375km)	200 μN
POWER	**20.5 W**
SC MASS (12U)	20 kg
ACCELERATION	1.0E-5 m/s²
ΔV RESIDUAL	230 m/s
DURATION	266 days

TILE3 (Accion)

DRAG (375km)	200 μN
POWER	**8.9 W**
SC MASS (12U)	20 kg
ACCELERATION	1.0E-5 m/s²
ΔV RESIDUAL	6 m/s
DURATION	6 days

NPT 30-12, 1.5U (ThrustMe)

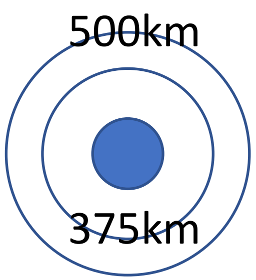
DRAG (375km)	200 μN
POWER	**17.8 W**
SC MASS (12U)	20 kg
ACCELERATION	1.0E-5 m/s²
ΔV RESIDUAL	201 m/s
DURATION	233 days

MPT (AASC)

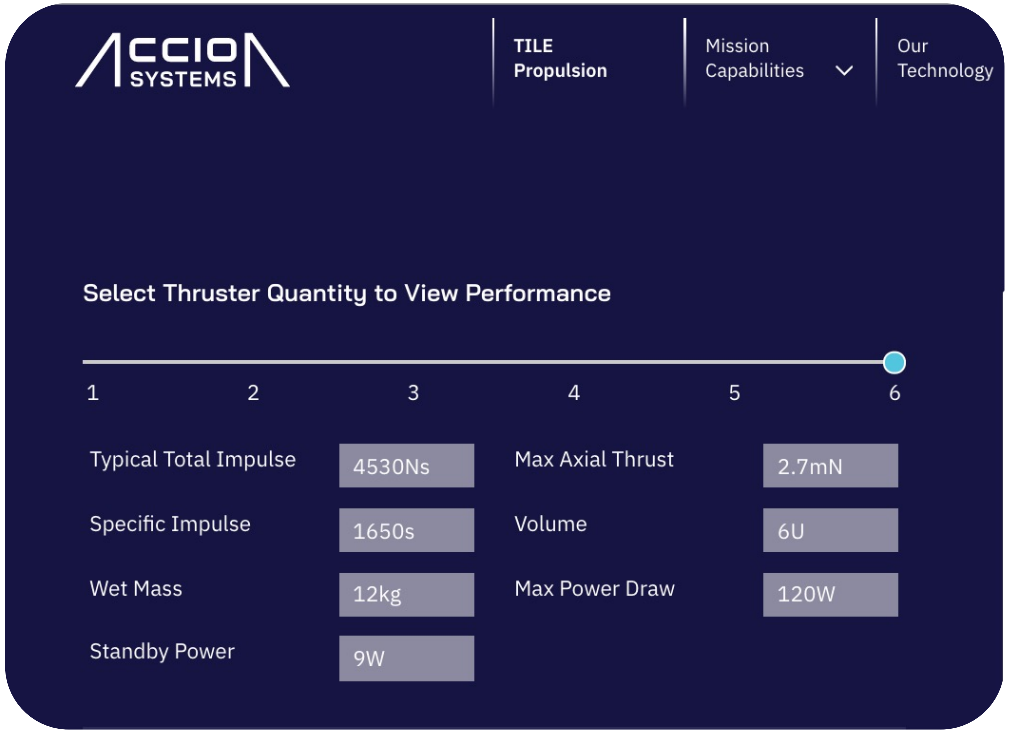
DRAG (375km)	200 μN
POWER	**16.6 W**
SC MASS (12U)	20 kg
ACCELERATION	1.0E-5 m/s²
ΔV RESIDUAL	179 m/s
DURATION	207 days

Mission 1: Part 3

Drag Compensation at 375km; use an array of TILE3 modules



- Multiple ACCION TILE3 modules provide higher total impulse
- An array of SIX TILE3 units would provide up to 4530Ns impulse, giving drag compensation in VLEO for a 12U for 181 days. The power draw would be only 9W.
- However, the Wet Mass of this array is 12kg, v. 1.0kg/1.7kg for the ENPULSION/AASC thrusters



TILE3 (Accion)	
DRAG (375km)	200 µN
POWER	**8.9 W**
SC MASS (12U)	20 kg
ACCELERATION	1.0E-5 m/s²
ΔV RESIDUAL	157 m/s
DURATION	181 days

THRUSTER	WET MASS (kg)	DRAG LIFE (days)
Enpulsion IFM Nano	1.032	266
AASC MPT	1.674	207
ACCION TILE3	12.000	181

Mission 2

Inject a 12U/22kg CubeSat into Lunar orbit (cis-lunar injection)

- 1km/s DV required for a CAPSTONE-like satellite
- Compare the candidates at 120W to fulfill a Lunar orbit insertion mission

IFM NANO (Enpulsion) | 4x Units

POWER	120 W
DRY MASS	2.60 kg
WET MASS	**4.62 kg**
VOLUME	**2.23 U**
ΔV TOTAL	1103 m/s
ΔV LUNAR INJECTION	1000 m/s
ΔV RESIDUAL	**103 m/s**

TILE3 (ACCION) | 6x Units

POWER	120 W
DRY MASS	11.57 kg
WET MASS	**12.00 kg**
VOLUME	**6.00 U**
ΔV TOTAL	227 m/s
ΔV LUNAR INJECTION	1000 m/s
ΔV RESIDUAL	-773 m/s

NPT 30-12, 1.5U (ThrustMe) | 2x Units

POWER	120 W
DRY MASS	2.00 kg
WET MASS	**4.85 kg**
VOLUME	**3.00 U**
ΔV TOTAL	961 m/s
ΔV LUNAR INJECTION	1000 m/s
ΔV RESIDUAL	-39 m/s

MPT (AASC) | 4x Units

POWER	120 W
DRY MASS	3.00 kg
WET MASS	**4.86 kg**
VOLUME	**3.71 U**
ΔV TOTAL	1083 m/s
ΔV LUNAR INJECTION	1000 m/s
ΔV RESIDUAL	**83 m/s**

- Only the IFM Nano and MPT both give additional ≈100m/s ΔV for in-orbit maneuvers

Assessment

A mission-based comparison

- Four EP candidates were compared for LEO and Cis-Lunar missions
- The IFM In FEEP, ThrustMe Iodine ion engine and MPT are comparable in Wet Mass/Volume for both missions; ACCION TILE is more massive
- ThrustMe Iodine engine contends with possible contamination[1] issues
- All but the MPT require standby power (to melt Indium, heat electrospray or vaporize Iodine) and for neutralizer guns
- The MPT:
  - Requires zero standby power, so when the CubeSat demands more power for other functions, the MPT may still be fired at <10W and provide thrust
  - The Molybdenum “pucks” of the MPT provide radiation shielding. The PPU may be remote from the “pucks” (deep inside the SC) for easier shielding
  - MPT arrays allow 2-axis rotation of the spacecraft (reaction wheel de-saturation)

1. Gabriel F. Benavides, Hani Kamhawi, Jonathan A. Mackey, and Thomas W. Haag, Gustavo C. C. Costa, NASA/TM—2018-219951