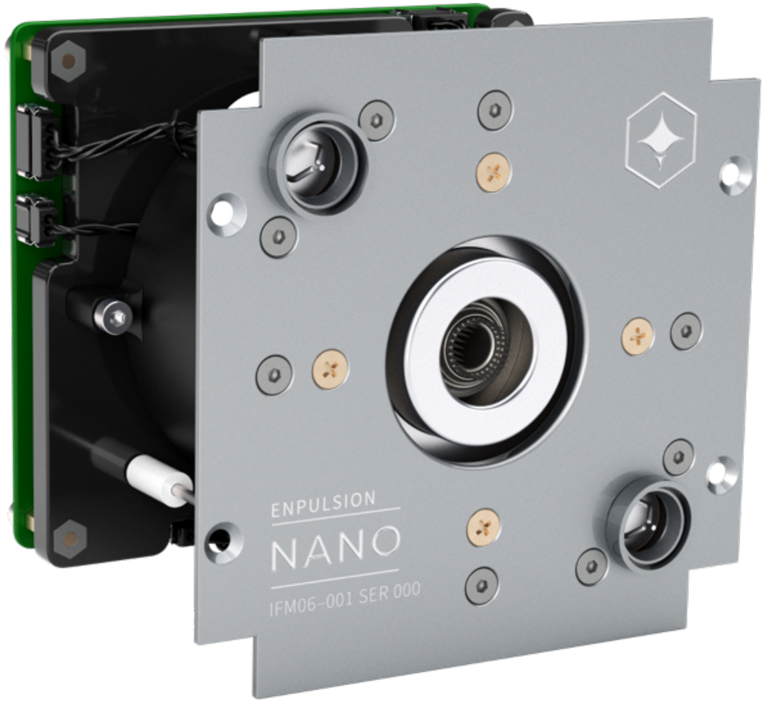
Modular FEEP propulsion systems for smallsatellite missions

David Krejci



FEEP Technology

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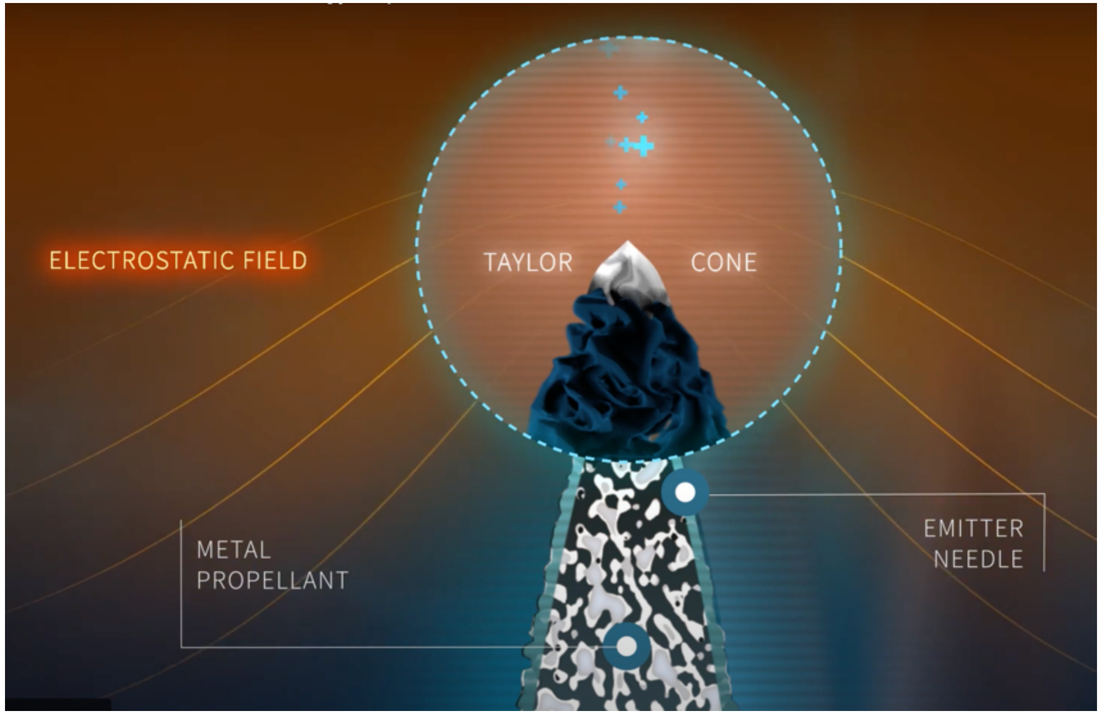
Electrostatic ion emission and acceleration from a Taylor cone

Operation at different Thrust and Specific impulse setpoints



Heritage in science missions

ENPULSION

>25 years of flight heritage in LMIS

The FEEP technology was developed at AIT (now FOTEC) for > 25 years for scientific missions, strong support through ESA

The IFM Thruster technology was developed by FOTEC based on this heritage

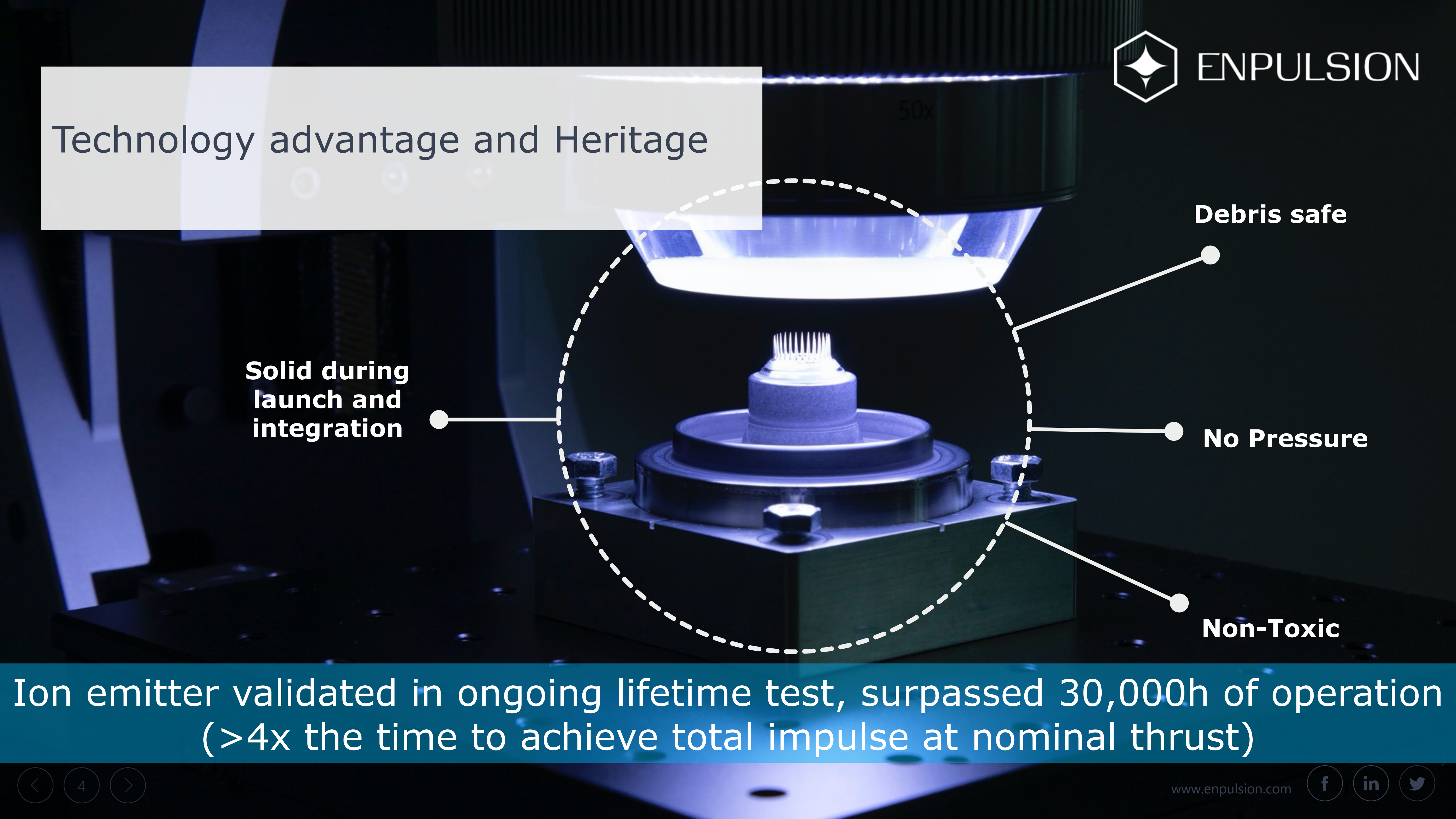
FOTEC Research Subsidiary of — FH Wiener Neustadt —

AIT/FOTEC Liquid Indium emitter flight missions

Experiment	Function	Spacecraft	No. of LMIS	Operation Time
LOGION	Test of LMIS in µ-Gravity	MIR	1	24 h (1991)
MIGMAS/A	Mass Spectrometer	MIR	1	120 h (1991-94)
EFE-IE	S/C Potential Control	GEOTAIL	8	600 h (1992 -)
PCD	S/C Potential Control	EQUATOR-S	8	250 h (1998)
ASPOC	S/C Potential Control	CLUSTER	32	Ariane 5 Launch Failure 1996 Still operational after Crash
ASPOC-II	S/C Potential Control	CLUSTER-II	32	6516 (2000 -)
COSIMA	Mass Spectrometer	ROSETTA	2	2004 - 2014
ASPOC/DSP	S/C Potential Control	DoubleStar	4	8979 h (2004 – 2007)
MMS ASPOC	S/C Potential Control	MMS	32	Commissioned successfully in 2015

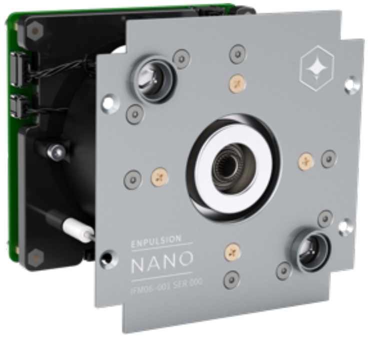
AIT AUSTRIAN INSTITUTE OF TECHNOLOGY → FOTEC Research Subsidiary of — FH Wiener Neustadt —

Technology advantage and Heritage

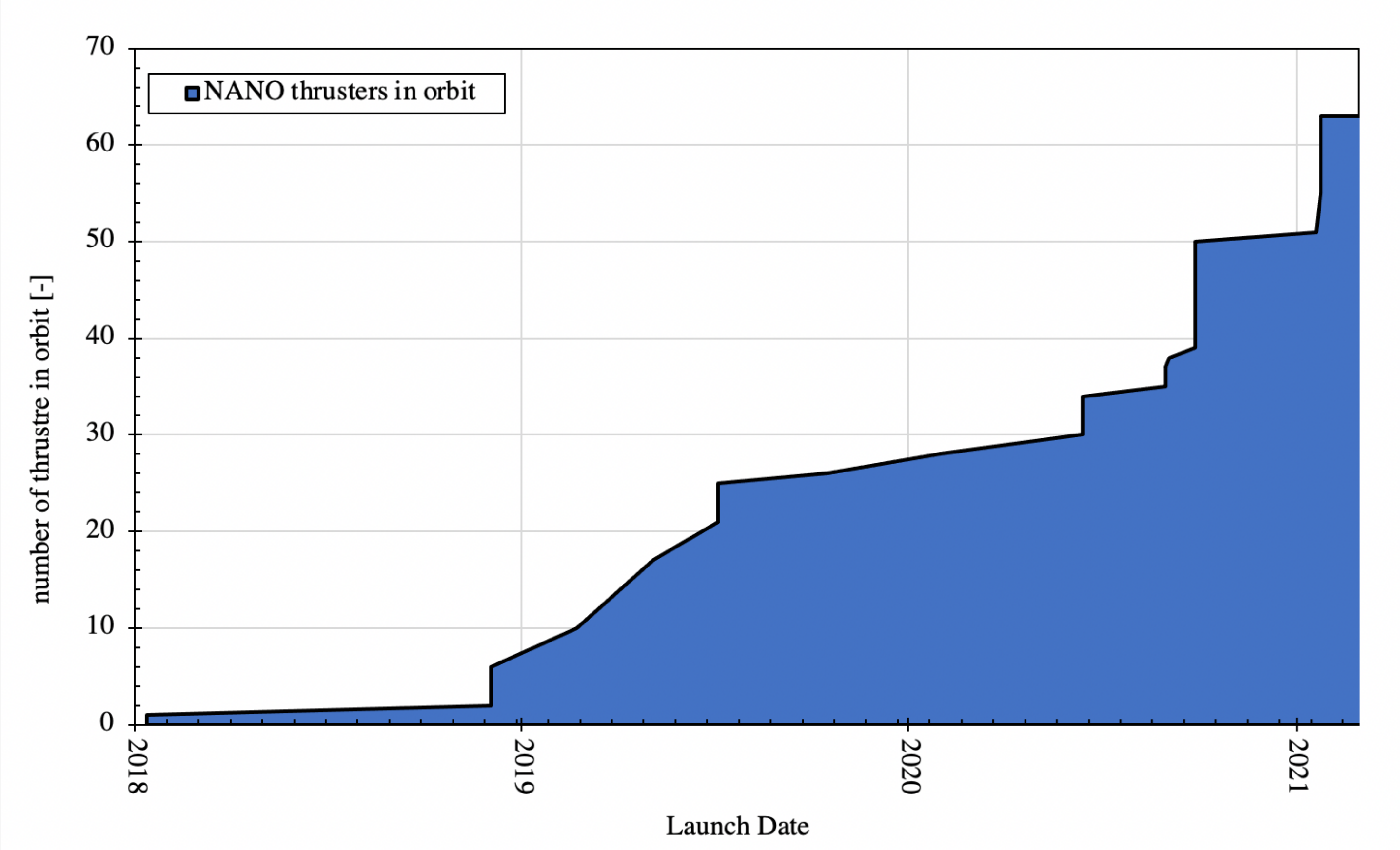


Ion emitter validated in ongoing lifetime test, surpassed 30,000h of operation (>4x the time to achieve total impulse at nominal thrust)

NANO Thruster Numbers



- 63 ENPULSION NANOs in orbit to date
- >180 FMs delivered



Verification of thrust model

ENPULSION

3U Cubesat

Conducted together with FOTEC Research Subsidiary of FH Wiener Neustadt

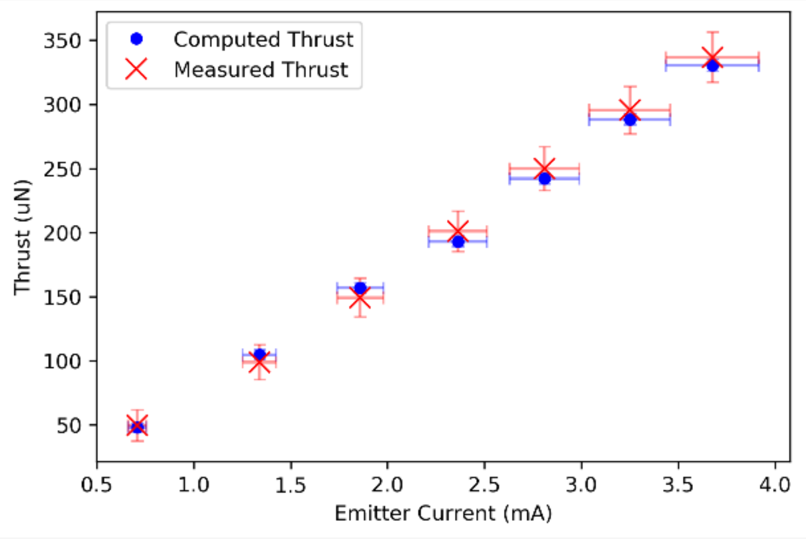
3U Cubesat (2018): Independent verification of thrust generation by measuring change of orbital parameters

Table 1. Change in average spacecraft semi-major axis due to thrust maneuver, measured from GPS data and calculated from propulsion telemetry

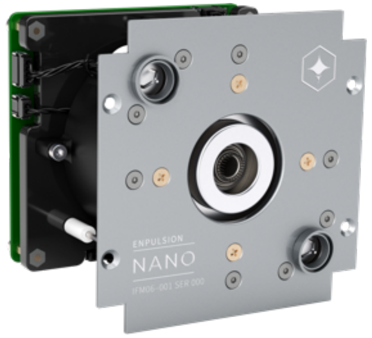
Maneuver parameters	**Average change in semi-major axis [m]**	
	Calculated from thruster telemetry	GPS measurements
Test 1: I_{em}=2mA, 15 min	72	70 ± 5
Test 2: I_{em}=2mA, 30 min	115	116 ± 5

From: Krejci et al: Demonstration of the IFM Nano FEEP Thruster in Low Earth Orbit, 4S symposium, 56, Sorrento, IT, 2018.

ESA thrust balance



From: Krejci, Hugonnaud, Schoenherr, Little, Reissner, Seifert, Koch, Bosch Borras, del Amo: Full Performance Mapping of the IFM Nano Thruster including Direct Thrust Measurements, submitted to JoSS



In-orbit data

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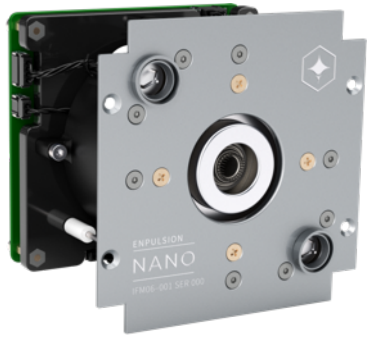
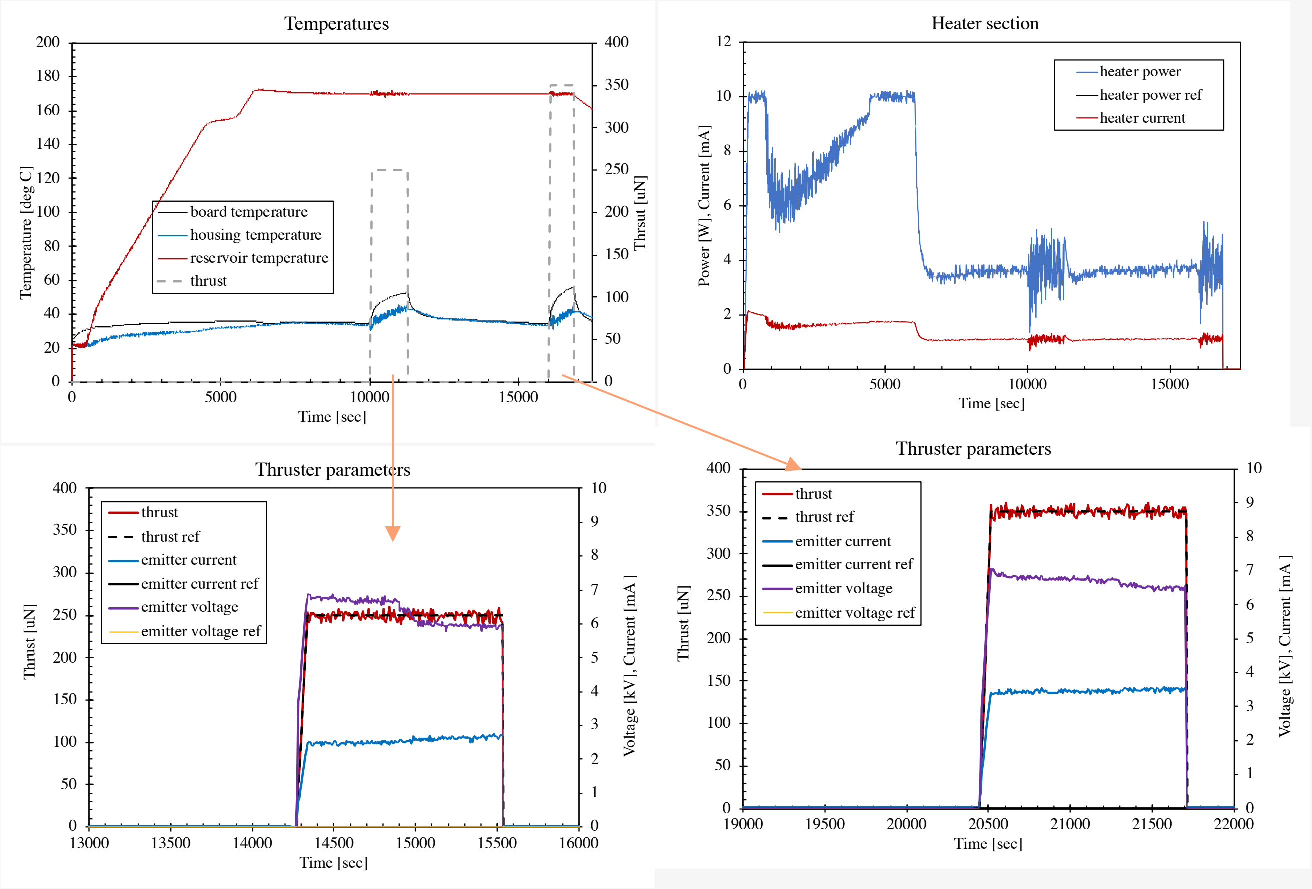
From:
Krejci, David, Reissner, Alexander, Schönherr, Tony, Seifert, Bernhard, Saleem, Zainab, Alejos, Ricardo: Recent flight data from IFM Nano Thrusters in a low earth orbit, 36th International Electric Propulsion Conference, IEPC-2019-724, Vienna, Austria, Spt 2019.



Telemetry data from
- Propellant liquification
- Hot-Standby
- Firings

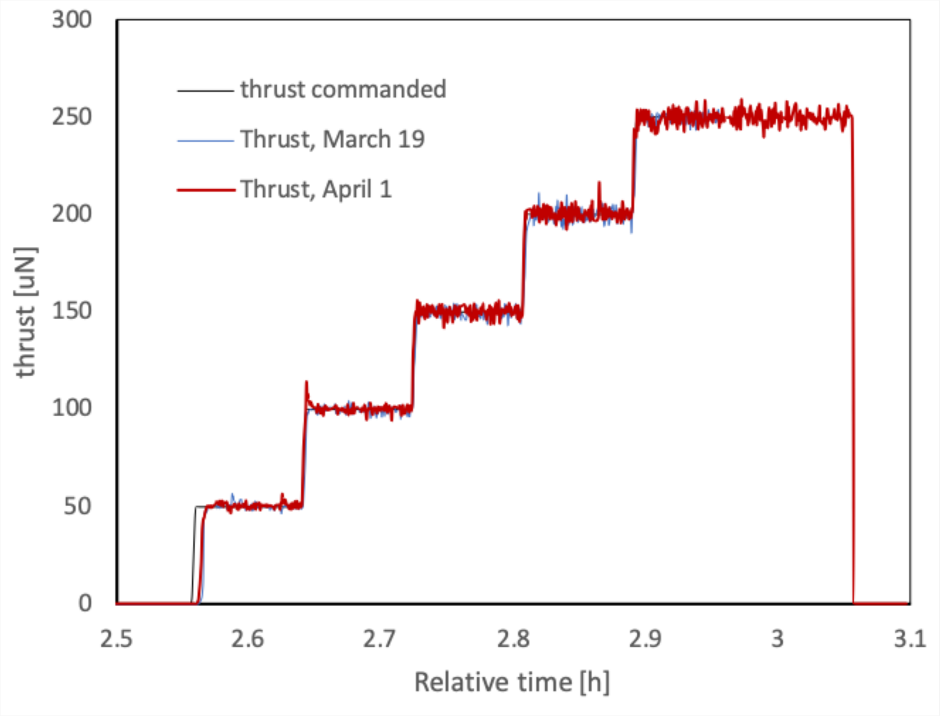


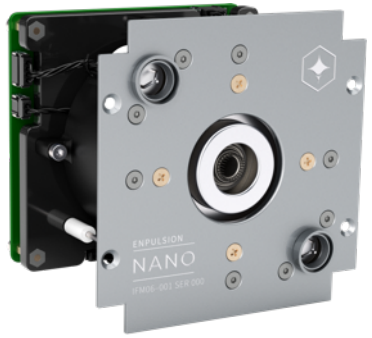
In-orbit data

3U IOD: Different s/c

1 year after commissioning

- Thrust steps with controlled transients
- Reproducibility of thrust profiles
- High Isp operation





SERIAL PRODUCTION OF FEEP PROPULSION SYSTEMS

ENPULSION

ENPULSION Production Line

ENPULSION

1 INCOMING INSPECTION
Batch inspection enables 100% incoming inspection, direct supplier feedback loop for continuous improvement

2 EMITTER PRODUCTION
Batch processing and semi-automation to increase throughput

3 PROPELLANT LOADING
Batch processing and semi-automatization to increase throughput

4 EMITTER CHARACTERIZATION
Parallel batch testing
Pre-selection data

5 SCANNING & PRE-SELECTION
Pre-selection based on statistical models from production allows early stage selection and continuous improvement

6 FINAL ASSEMBLY
Streamlined pull processes decrease cycle times customization options

7 THERMAL ACCEPTANCE TESTING
Parallel batch testing incorporating customer acceptance requirements

8 VIBRATION TESTING
Parallel batch testing incorporating customer acceptance requirements

9 FUNCTIONAL ACCEPTANCE
Parallel batch testing and semi-automatization reduce average process times

10 FINAL INSPECTION & SHIPPING
High rate processes developed with customer feedback loop

Manufacturing data as statistic for improvement

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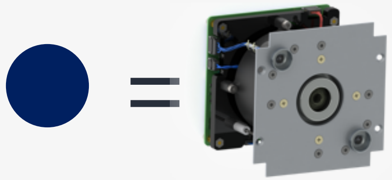
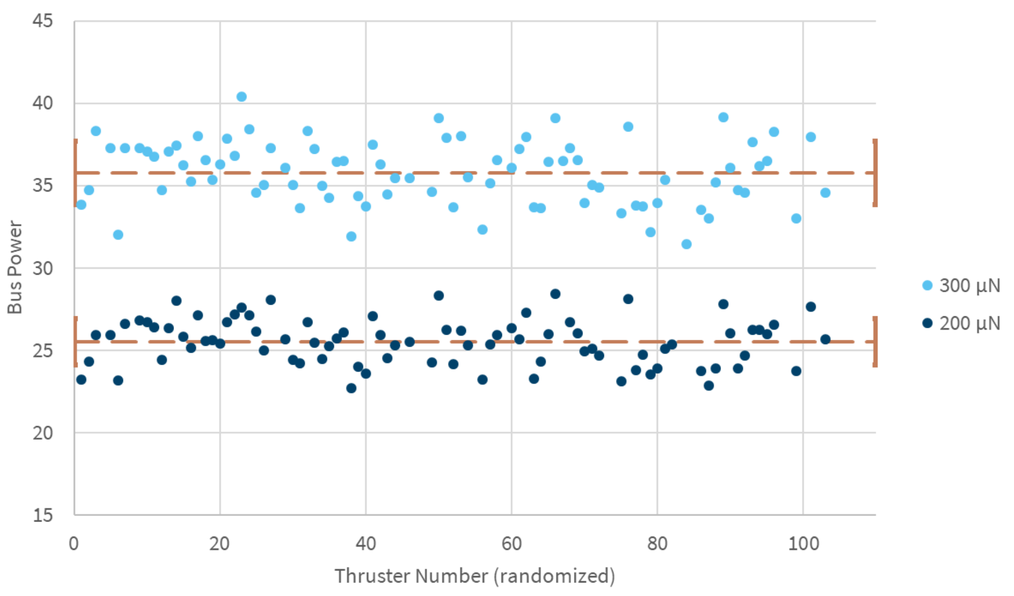
Acceptance data statistics first 100 FMs

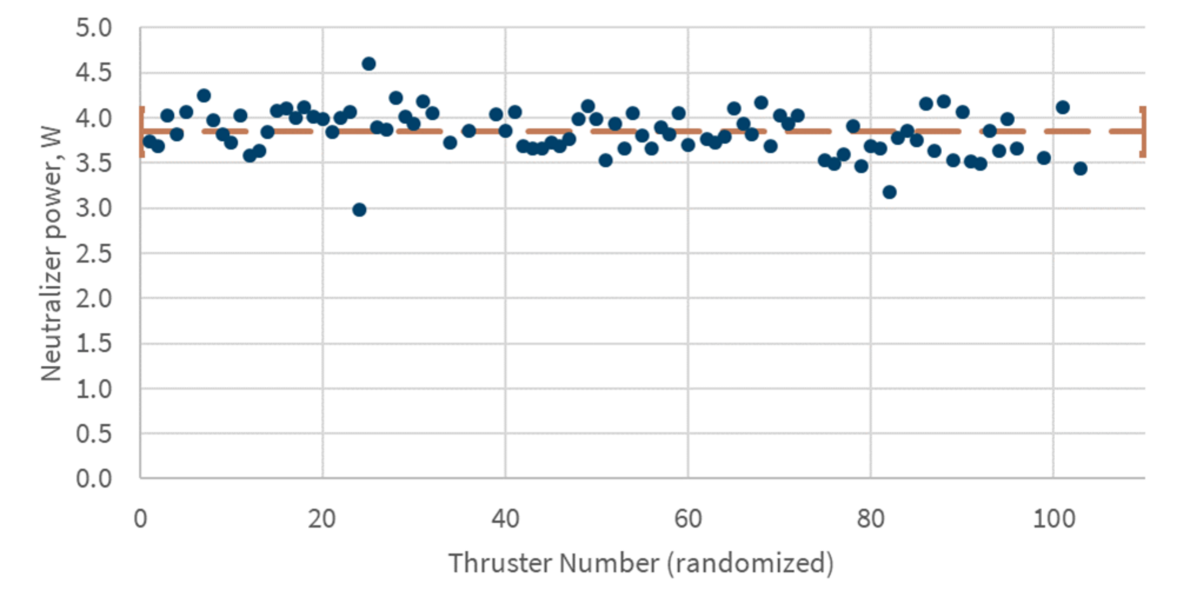
Large number of thrusters allows to leverage statistical tools

Each data point represents a flight model



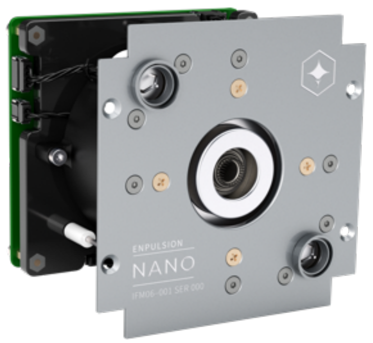
Spread in data is relating to thrusters optimized for different operational regimes



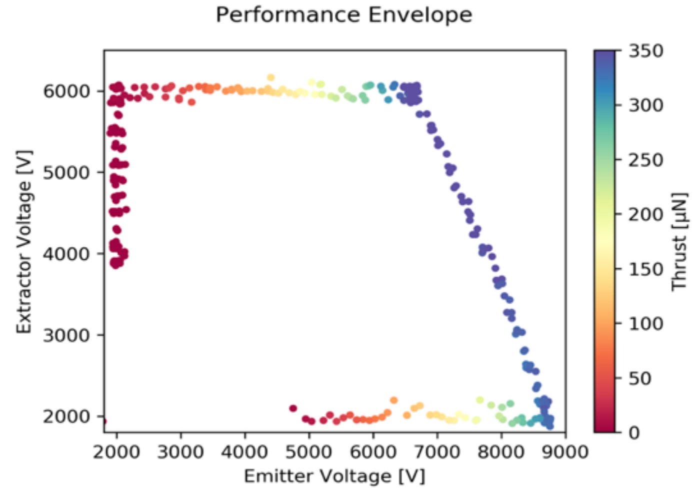


NANO Thruster Testing

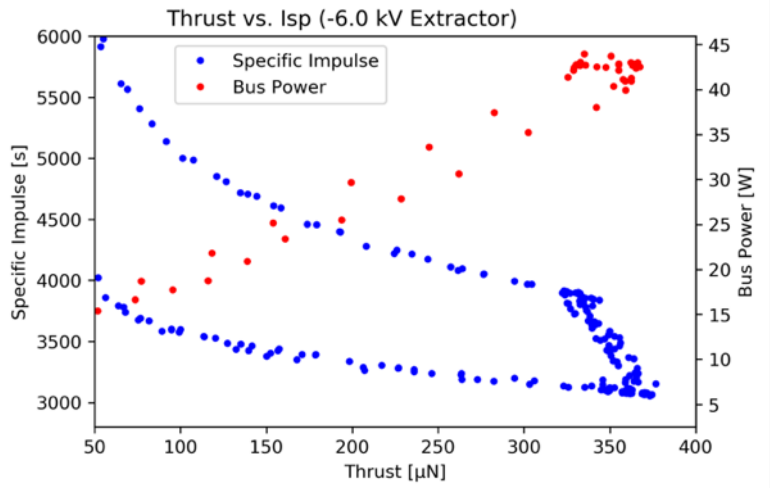
Standardized acceptance testing

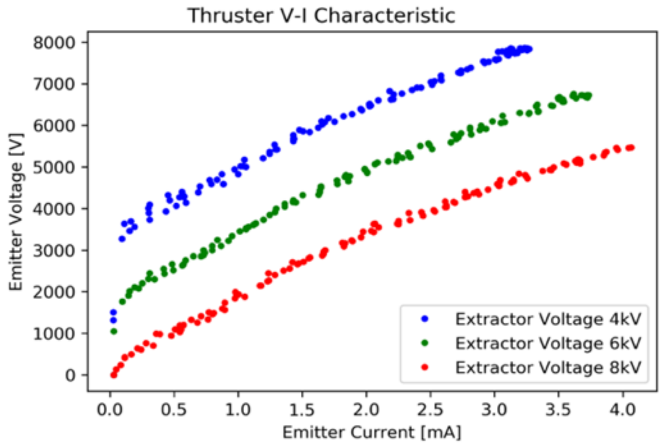


Thruster performance envelope (emitter and extractor potential)

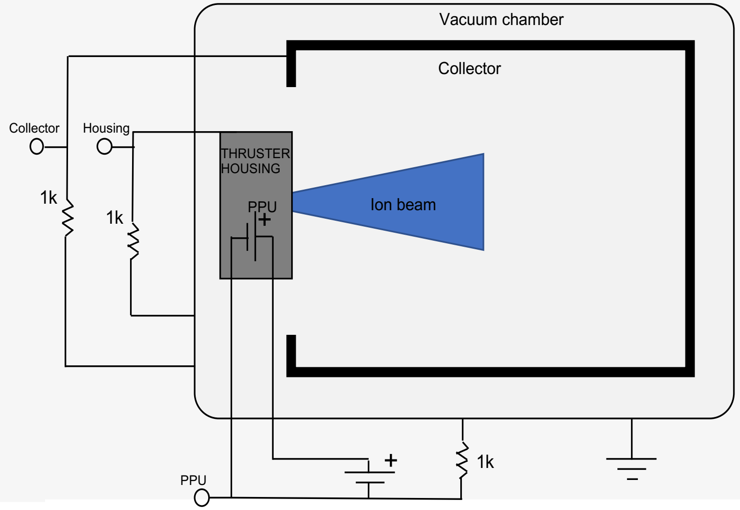


Thruster performance envelope (reduced envelope to -6kV)





Thruster I-V curves (emitter startup voltage & impedance)

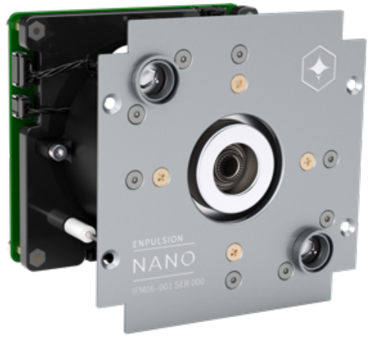


Direct neutralization verification

NANO Thruster Testing

ENPULSION

Standardized acceptance testing



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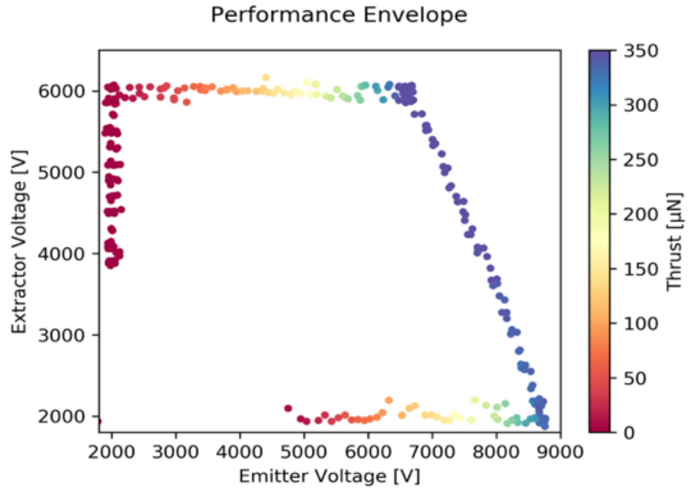

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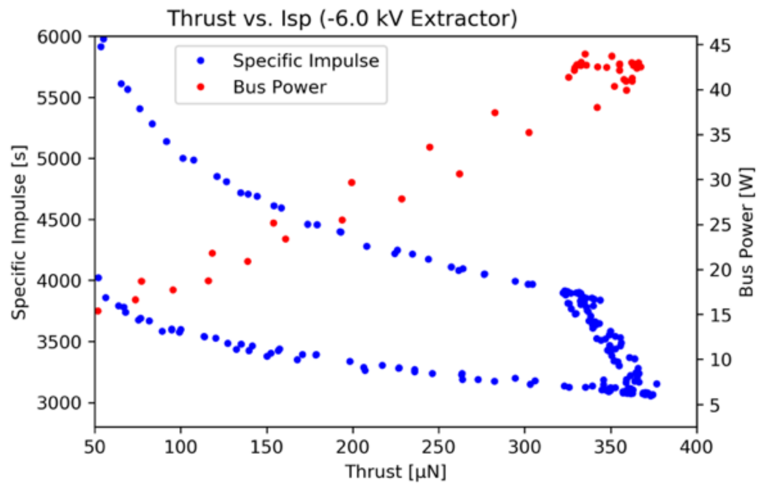

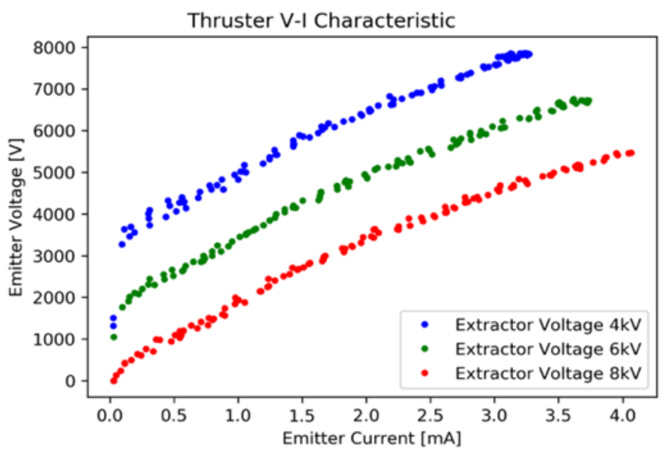

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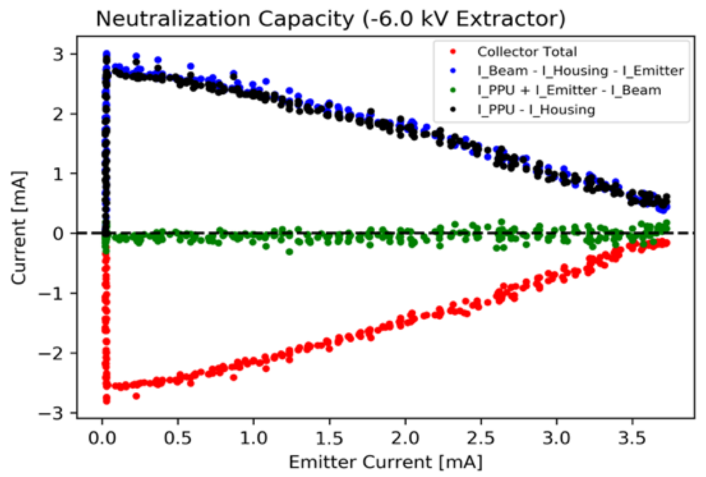
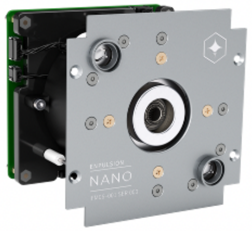
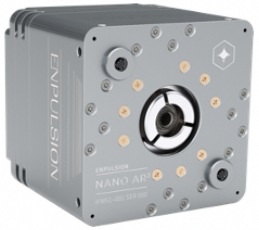


Direct neutralization verification

Next generation: NANO R3 thrusters

ENPULSION





	ENPULSION NANO	ENPULSION NANO R^3	ENPULSION NANO AR^3	ENPULSION NANO IR^3	ENPULSION MICRO R^3
	FLIGHT HERITAGE	ROBUST	VERSATILE	POWERFUL	**DURABLE**
DYNAMIC THRUST RANGE	**10 µN TO 350 µN**	**10 µN TO 350 µN**	**10 µN TO 0.35 mN**	**10 µN TO 500 µN**	**200 µN - 1.35 mN**
NOMINAL THRUST	**330 µN**	**350 µN**	**350 µN**	**500 µN**	**1 mN**
SPECIFIC IMPULSE	**2,000 TO 6,000 s**	**2,000 TO 6,000 s**	**2,000 TO 6,000 s**	**1,500 TO 4,000 s**	**1,500 - 6,000 s**
PROPELLANT MASS	**220 g ± 5%**	**220 g**	**220 g**	**220 g**	**1.3 kg**
TOTAL IMPULSE	**MORE THAN 5,000 Ns**	**MORE THAN 5,000 Ns**	**MORE THAN 5,000 Ns**	**MORE THAN 4,000 Ns**	**MORE THAN 50,000 Ns**
TOTAL SYSTEM POWER	**8 – 40 W**	**8 – 40 W**	**8 – 40 W**	**8 – 45 W**	**30 - 120 W**
POWER AT NOMINAL THRUST (incl. Heating and Neutralizer)	**40 W**	**40 W**	**40 W**	**45 W**	**90 - 100 W**

NANO R3 Thrusters

Modular

Increased resilience

Based on the heritage NANO
- thruster design
- key components: emitter/reservoir
- production line

Improved PPU design
- TID, SEE, higher control logic

Added capabilities

Thrust vector capability

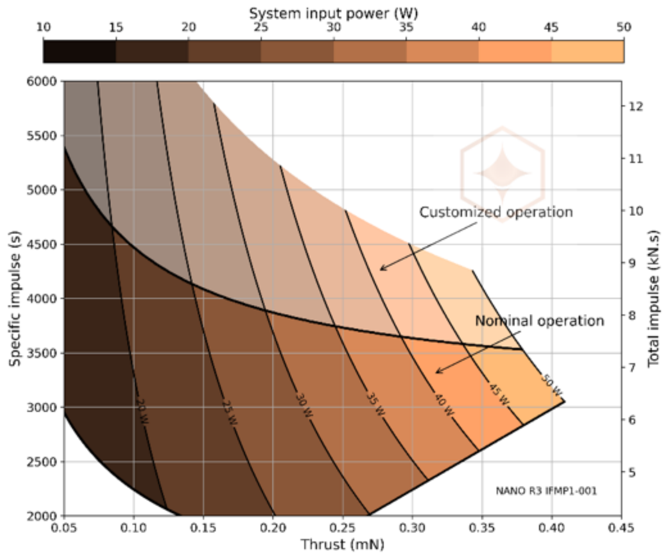
Increased thrust / lower Isp operation

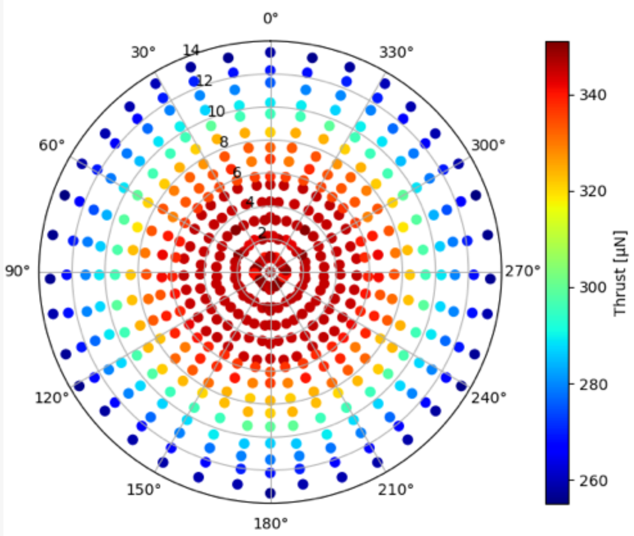
NANO R3 Thrusters

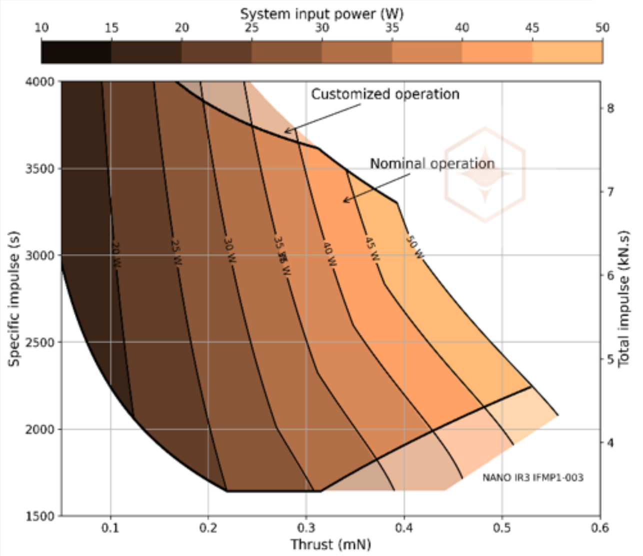
ENPULSION

Modular

Increased resilience



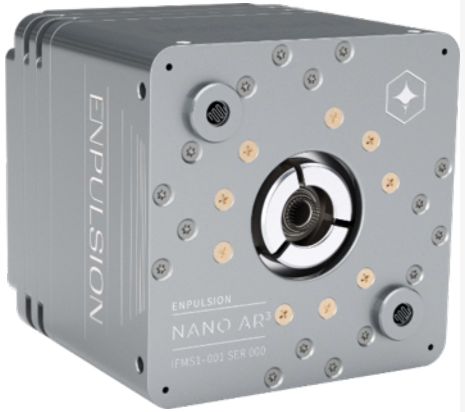




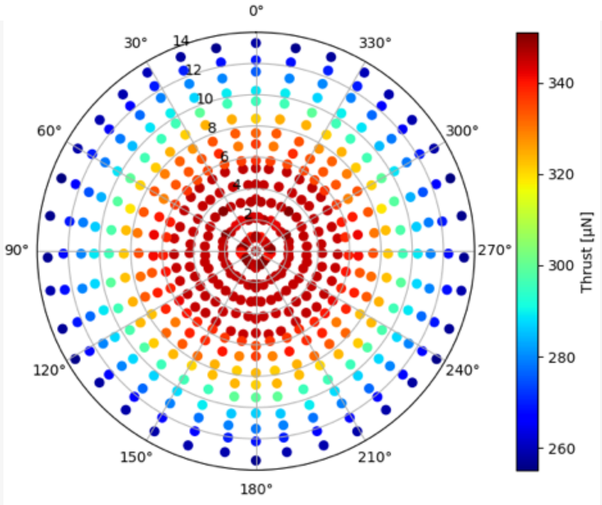
NANO AR3: Thrust vectoring

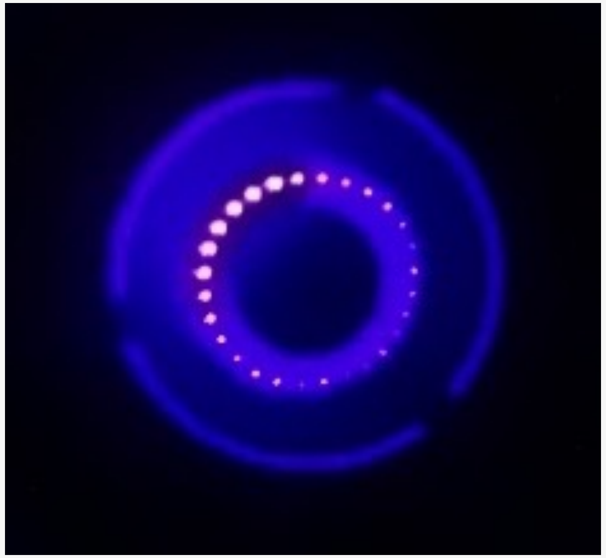
ENPULSION

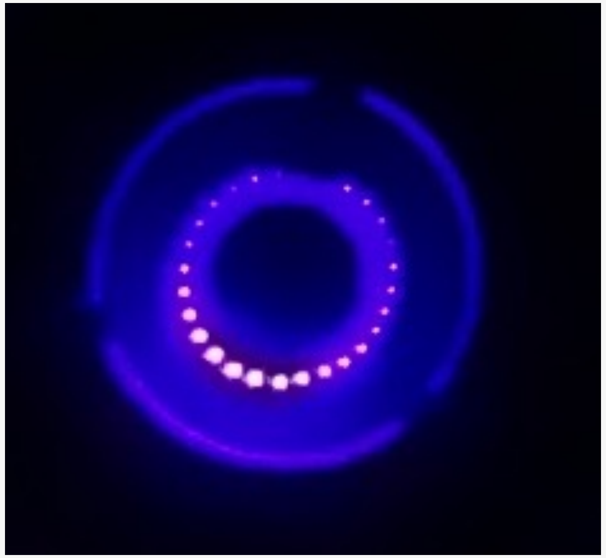
Differential throttling

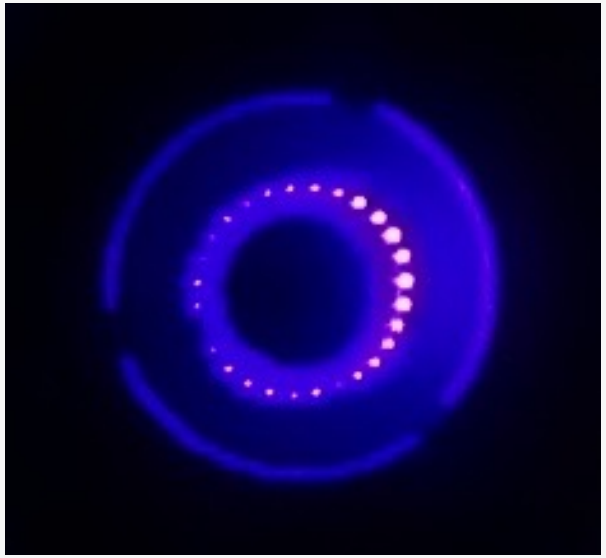


Thrust vectoring by differential throttling
- No movable parts
- Reduced thrust at higher angles









ENPUSION Family: Space Heritage

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	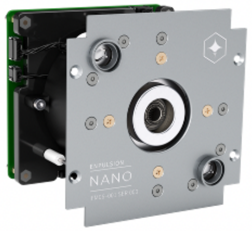		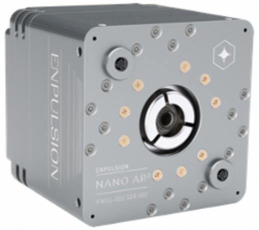		
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MICRO Thruster Update

ENPULSION

First MICRO R3 verified in space

- Commissioning ✓
- Orbit change maneuver ✓

ENPULSION PRODUCTS TECHNOLOGY VISION ORDER NOW

OHB SWEDEN CONFIRMS SUCCESSFUL IN-ORBIT COMMISSIONING AND FIRST USE OF THE ENPULSION MICRO R³ THRUSTER IN THE GMS-T MISSION

→ News →

OHB Sweden confirms successful in-orbit commissioning and first use of the ENPULSION MICRO R³ thruster in the GMS-T mission

ENPULSION OHB SWEDEN

Wiener Neustadt, Austria, March 15th, 2021 –Today ENPULSION, the market leader in small satellite propulsion with more than 60 thrusters in space, confirmed the first successful in-orbit commissioning and first uses of its new ENPULSION MICRO R³ thruster. Its partner OHB Sweden said in a statement:

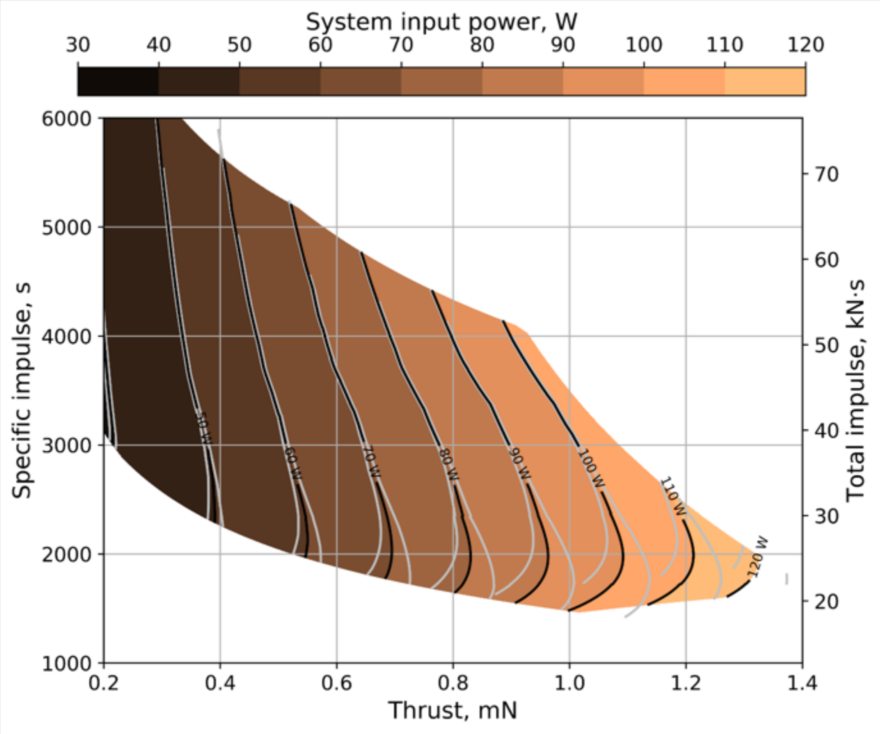
"We are keen to report on GMS-T that the in-orbit commissioning and first uses of the ENPULSION MICRO thruster have been completed as expected in the mission. The GMS-T mission is based on OHB Sweden's InnoSat-light platform." For more information on InnoSat please refer to the website of OHB Sweden.

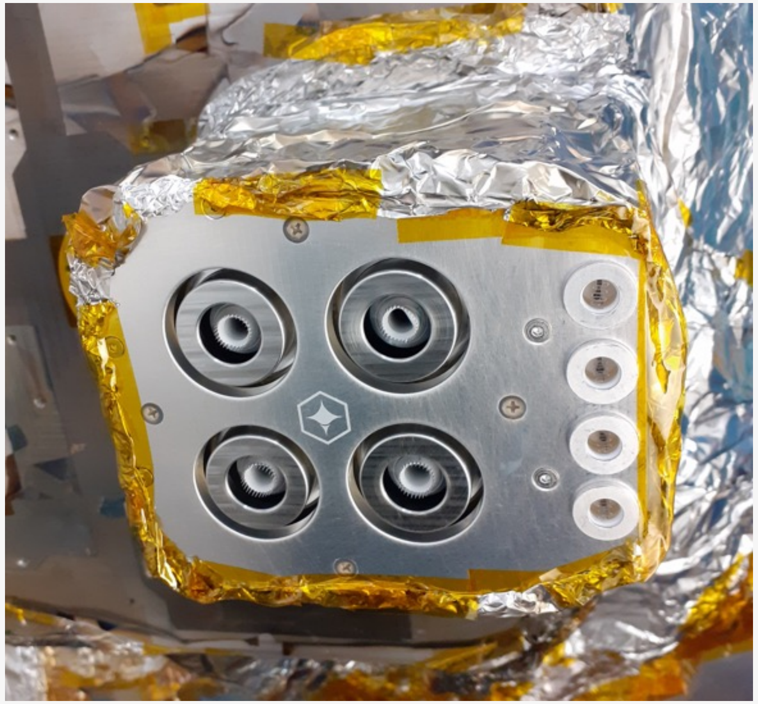
Within the GMS-T mission OHB Sweden is the prime contractor for the design, development, integration, and test of the Innosat-based platform of a small telecommunication satellite (50kg-class). This satellite will be used for delivering signals for the Bringing Into Use (BIU) of telecommunication frequencies for an international commercial customer. The company is also responsible on full system level for the spacecraft integration and testing activities. GMS-T was launched on the 20th of January 2021 onboard Rocket Lab's 18th Electron launch mission "Another One Leaves The Crust".

From: enpulsion.com

MICRO Thruster Update

MICRO R3





Acceptance testing of MICRO

Conclusion

Thrust	Thrust model confirmed through ground testing in different facilities, and by orbital changes
NANO R3	Modular thruster design Improved PPU while leveraging extensive NANO heritage in key component design and production capabilities
Flight heritage	Building up extensive space heritage, feeding lessons learnt into the design of new propulsion system generations. 63 NANO thrusters in space 1 MICRO R3 thruster in space

ENPULSION

THANK YOU

Are there any questions?

Not all launches shown. In case of undisclosed customers, sample images are shown

ENPULSION

SPACECRAFT TECHNOLOGY

MARKET LEADER FOR SMALL SAT PROPULSION