National Aeronautics and Space Administration

Ames
Discovery Innovations Solutions

Highly integrated propulsion system for CubeSat applications - µCAT

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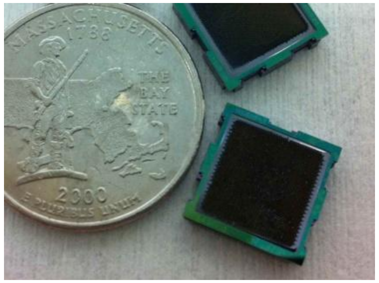
Agenda

1. Introduction - Electric Propulsion for CubeSats
2. Vacuum Arc Thrusters - µCAT
3. NASA Ames-GWU Micropropulsion system
4. PCB development
5. Testing
6. Conclusions

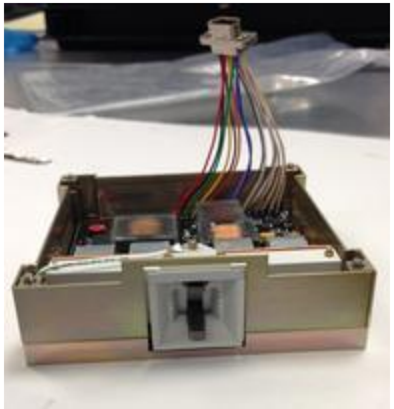
Electric propulsion for CubeSats

- Various technologies:
  - **Ion engines**
  - **Resistojets**
  - **Hall Thrusters**
  - **Field Emission Propulsion**
  - **Pulsed Plasma thrusters**
  - **Magnetoplasmadynamic (MPD) thrusters**
  - **Ion Electrospray Thrusters**

BIT-3 ion engine, Busek



Electrospray, MIT



Pulsed Plasma Thruster, Mars & Clyde Space

Currently, no electric propulsion system has shown robust performance in a CubeSat flight demonstration

Electric propulsion for CubeSats
State of the art

Advantages

•Low complexity with respect to chemical propulsion

•Affordable and high grade of feasibility

•High specific impulse enables more mission concepts

•Various promising technologies

Problems

•Low Technology Readiness Level (TRL)

•Low robustness: need of a solid technology demonstration

•Miniaturization from larger versions is challenging

•Power, mass and volume are limited

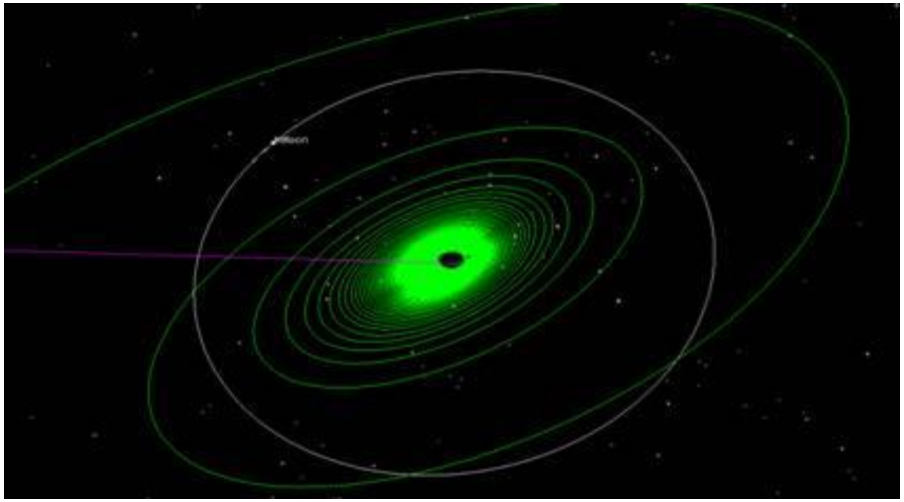
Lack of standards for test procedures, results, performance and technology demonstration

Electric propulsion for CubeSats: Main applications

Large ΔV Maneuvers

- Thrust in the range of 1-100 mN
- Capable of performing spiral trajectories to achieve high accelerations
- Relatively high power consumption and mass/volume requirements
- Examples: Cubesat Ambipolar Thruster, Array of iEPS microthrusters, ion thrusters…

Thruster	I_{sp}	Thrust	Power
CAT	1000 s	20 mN	100 W (adjustable 3-300 W)
BFIT-3	3500 s	1.4 mN	60 W
Array of iEPS	2500 s	2.28 mN	40 W



ADCS / Station-Keeping

- Low thrust ranges : 1-100 µN
- Very high specific impulse
- Low complexity
- Low minimum impulse bit
- Low power requirements
- Low volume and mass requirements

- Examples: Pulsed Plasma Thrusters (PPT), vacuum arc thrusters (µCAT)

PPT	I_{sp}	Power	Mass	Electrodes	Propellant	I_{bit}
Busek	443 s	5 W	1.7 kg	Annular	Teflon	86 µNs
Clyde Space	608 s	2.7 W	180 g	Side fed	Teflon	30.6 µNs
µCAT	3000 s	1 W (depending on pulse frequency)	200 g	Coaxial	Titanium	0.1µNs

µCAT thruster

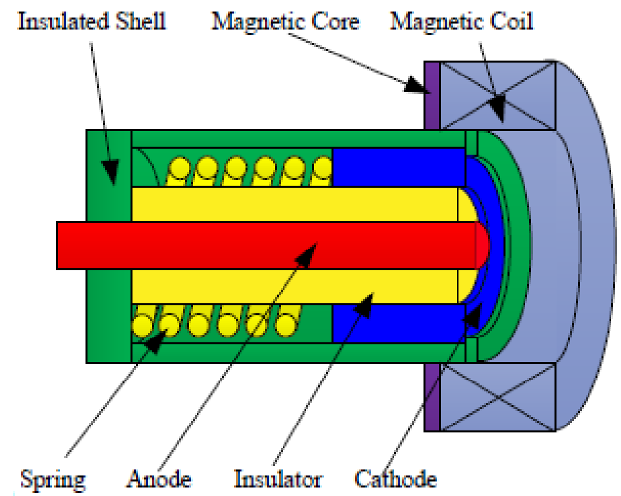
Ablative discharge of a titanium solid propellant rod

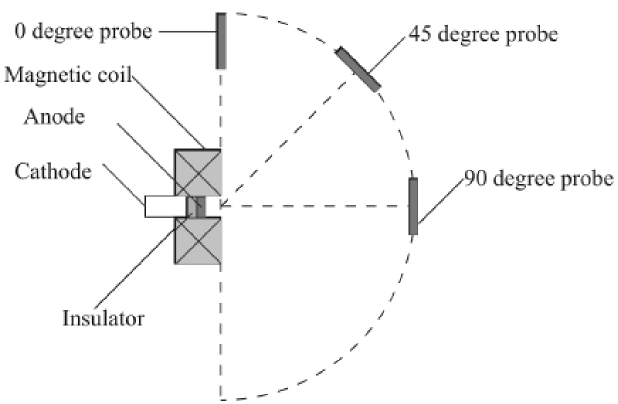
Quasi-perfect ionized plasma (99%)

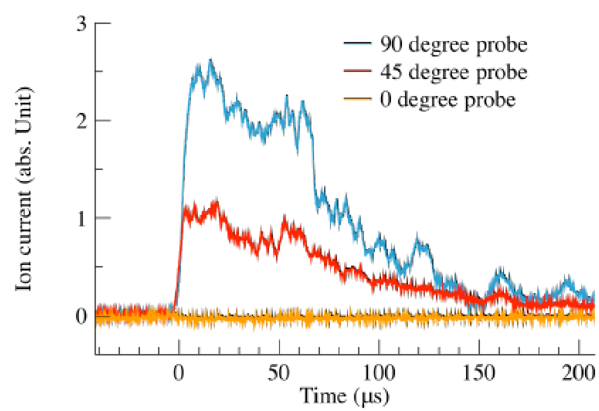
Zero back-flux

- Higher thrust efficiency
- Avoidance of potential hazardous interactions

Specific impulse in the range of 2000-3000s

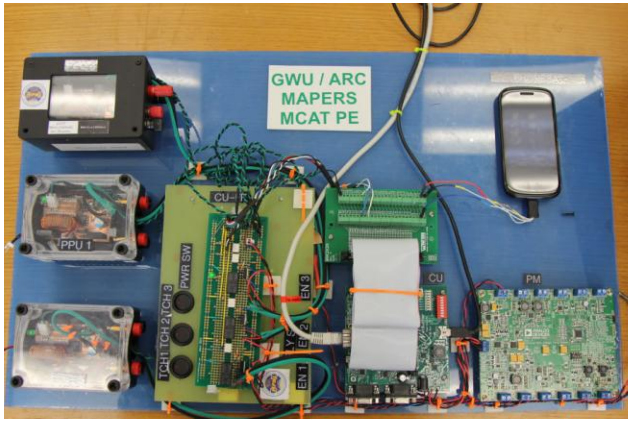






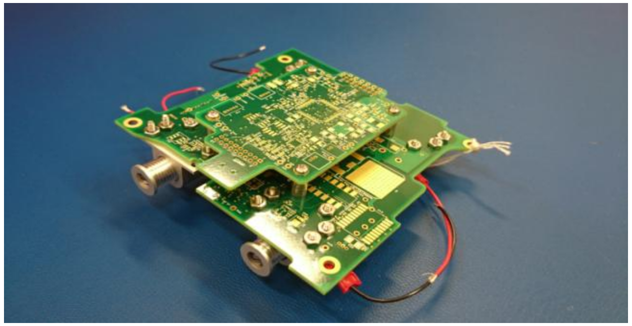
Micro-Cathode Arc Thruster for PhoneSat Propulsion, M. Keidar et al., 2013

NASA Ames – GWU µCAT propulsion system joint project



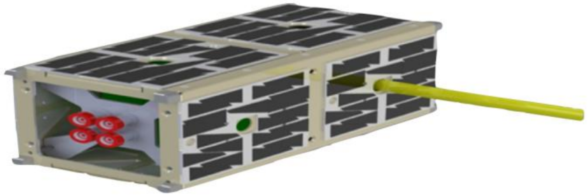
2013 initial project: control and operate 3 thrusters with the PhoneSat software. Flat-Sat integration

Tested in vacuum chamber, August 2013



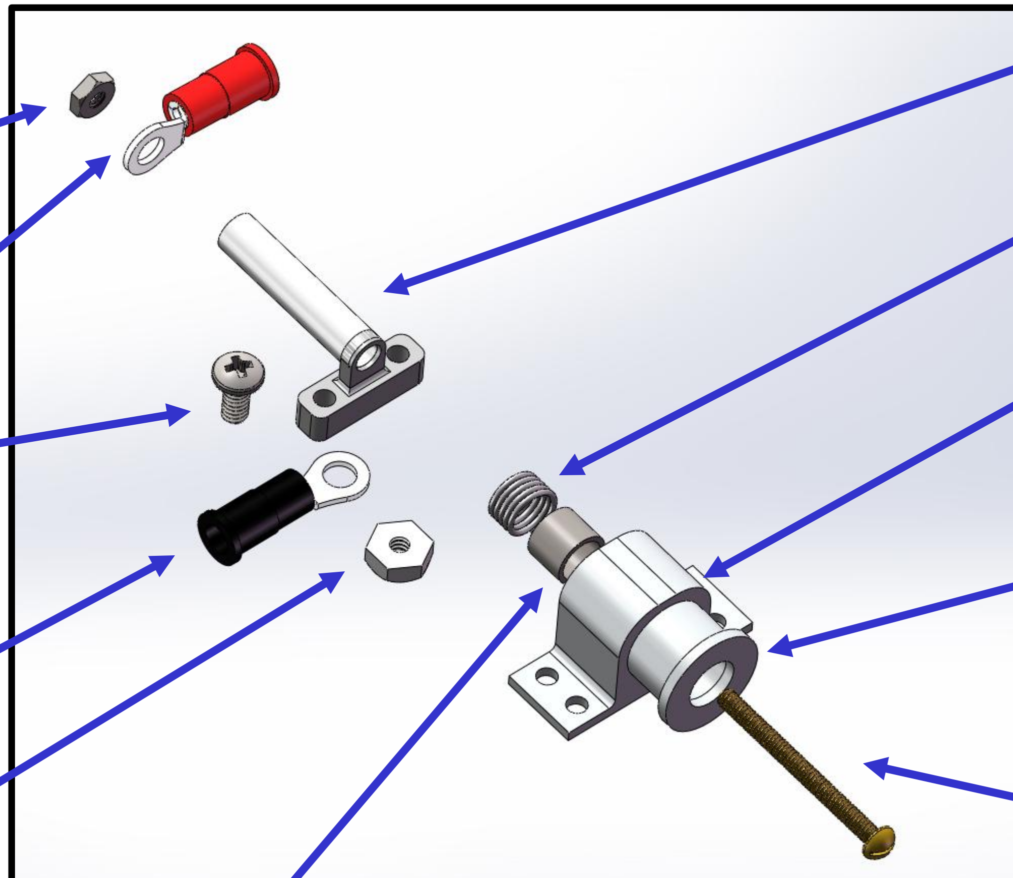
2014 project: thrusters integrated in a single PCB compatible with the PhoneSat/EDSN bus

2015 achievement: Thrusters tested at Glenn Research Center



<u>Next goal</u>: perform a CubeSat flight demonstration mission

Thruster head CAD design



PCB development

Mechanical Design

- <0.2 U volume
- Based on EDSN Lithium board
- Each board accommodates up to four thrusters

Electrical design

- Any possible firing combination is performed by the control logics implement in the circuit
- Boards are completely compatible with any bus with a UART communication interface. Plug and play approach

Software design

- Small control board to program thruster operations
- Selection of various frequencies available (power and thrust control)

Software – PWM control

- A high voltage arc is required to create the plasma needed to ablate the cathode. The high voltage arc is created by fully charging an inductor/capacitor circuit, then discharging this circuit very quickly

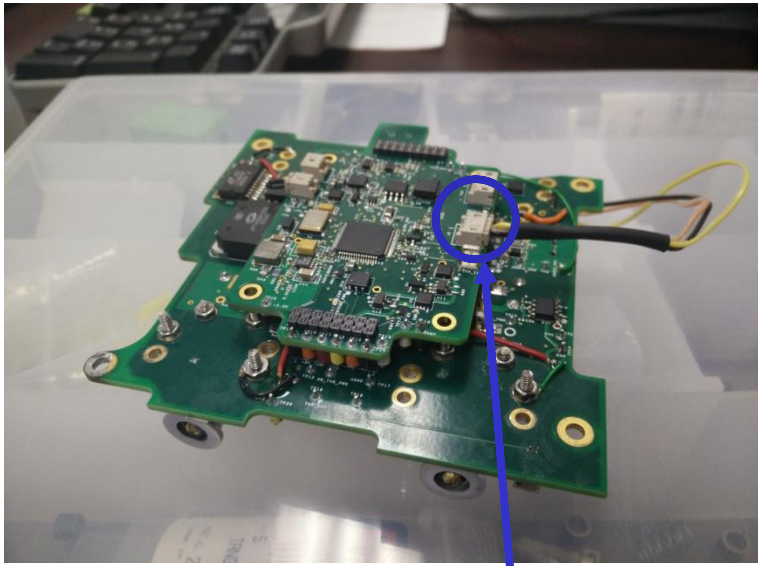
- The precise charging/discharging circuit is controlled using PWM pulses. The width of the pulse as well as the time between pulses can be set by software to finely tune the characteristics of the thruster

Software – Testing interface

- The thruster board is controlled using commands sent over an UART connection

- Thruster Control Parameters:
  - Channel: which combination of thrusters are firing
  - Duty Cycle: how often the thruster will fire
  - Pulse Width: width of the pulse used to create the voltage arc
  - Runtime: length of time that pulses will be generated

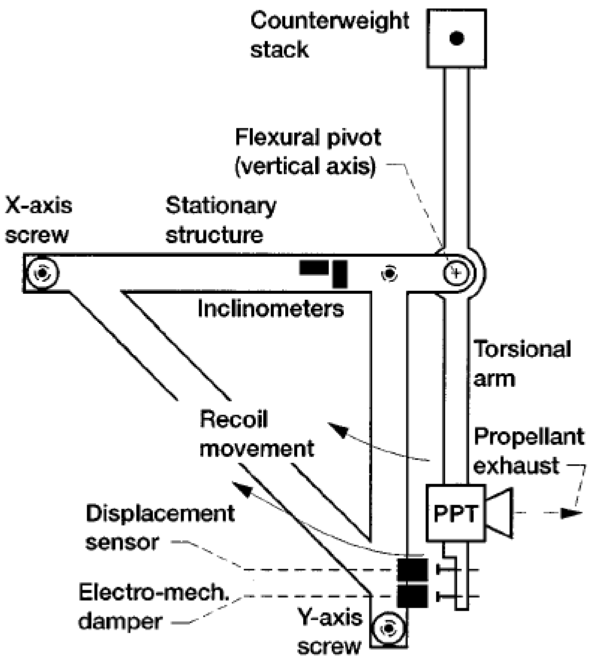
- These parameters can be used to finely tune the thruster performance for testing or ADCS applications



UART connection

Glenn Research Center thrust stand tests – December 2014

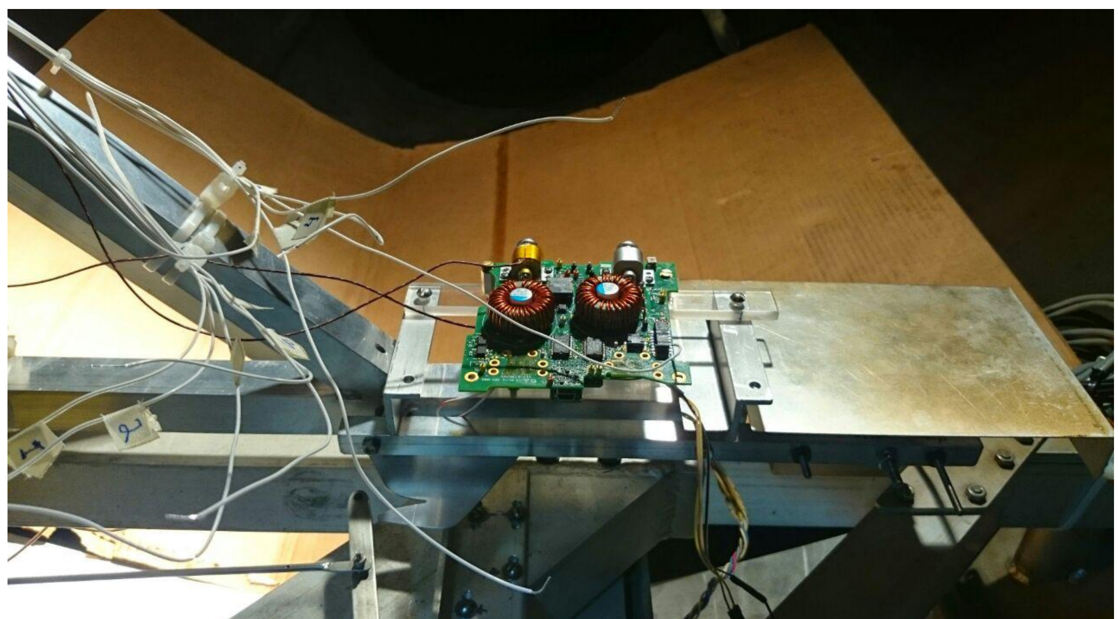
- Performed at NASA Glenn Research Center with a high accurate torsional thrust stand
- Several measurements at 10,25,50 and 75 Hz operating frequency
- Thrust stand displacement with the damper disengaged determined impulse measurements



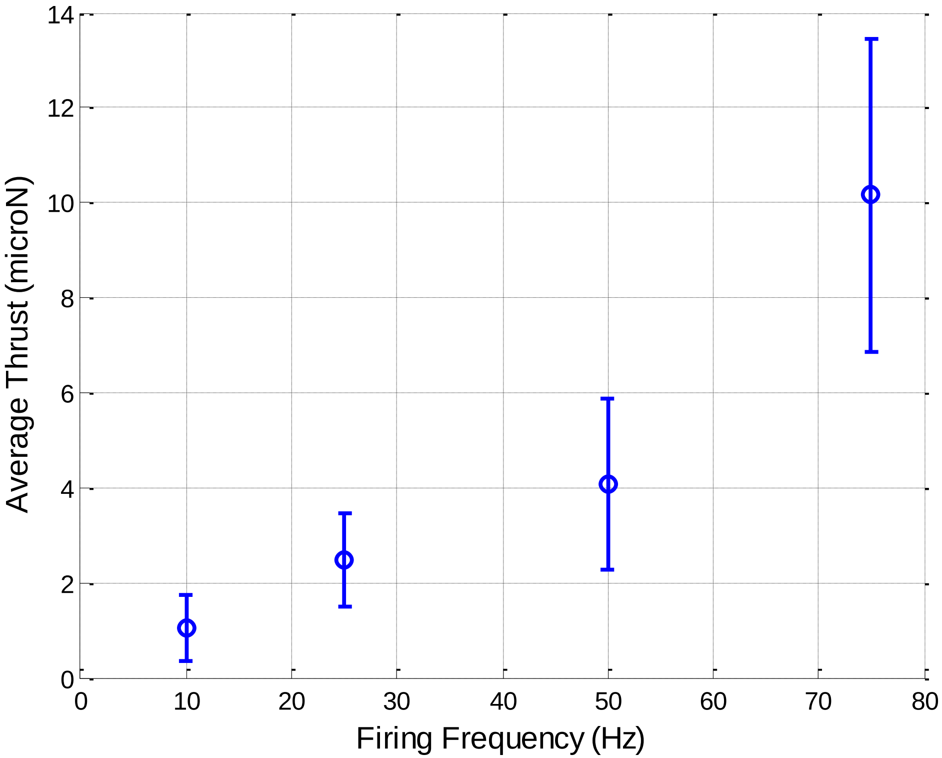
Thrust Stand for Pulsed plasma thrusters, T.W. Haag, NASA Lewis Research Center, 1996

Test performance

- Short measurements: 1-5 seconds each
- Point of maximum displacement recorded and analyzed to calculate total impulse
- Electrical leads to connect to power supply and to command board to test various configurations
- Thermal Couplers to measure overheat in thruster and key circuit components (IGBT)
- Pressure of the vacuum chamber during test: 4.5E-6 Torr
- No substantial overheat was detected in the test (either thruster head or electronics). Long operation test still required



Average thrust results



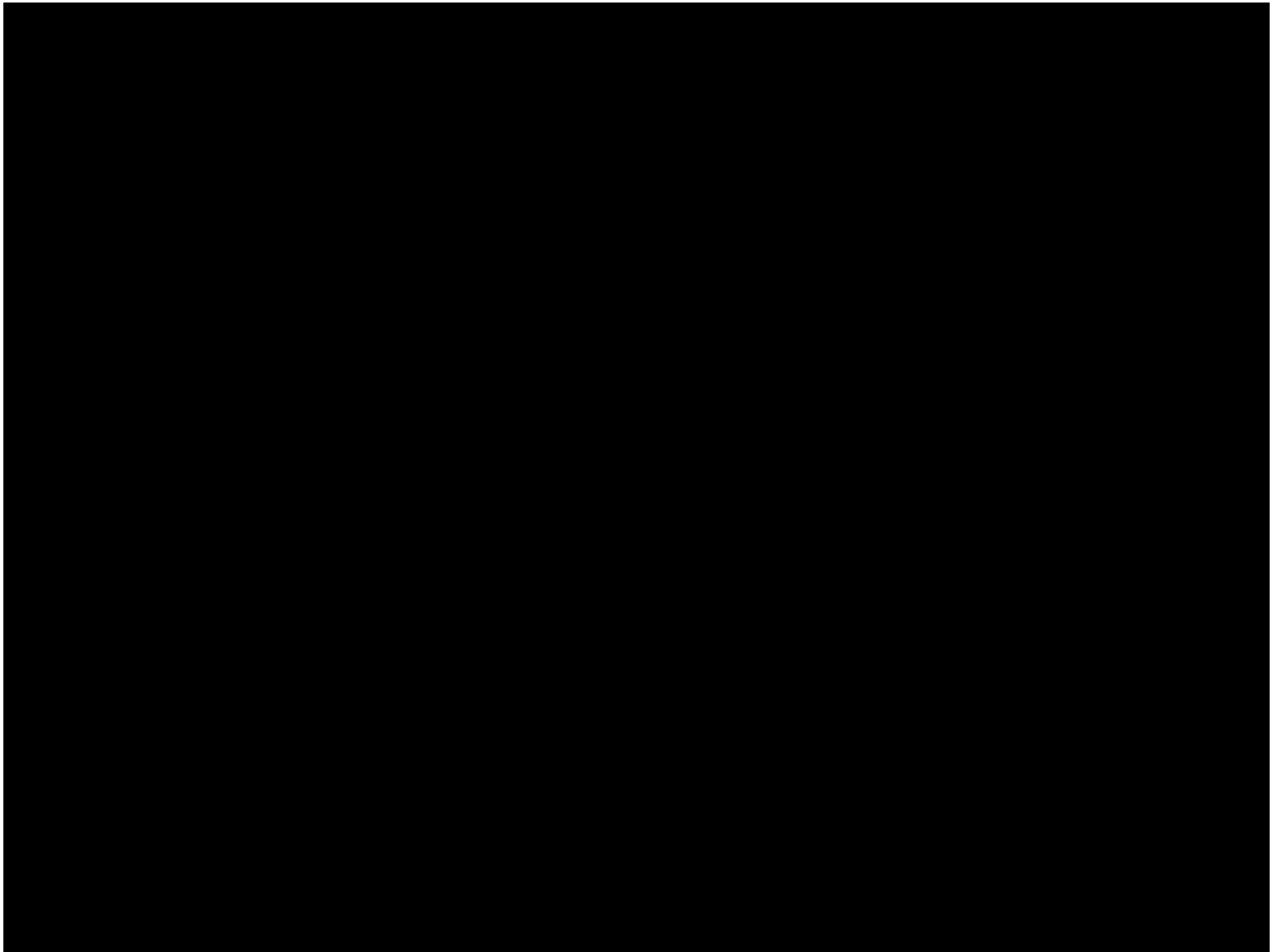
Average thrust is directly proportional to operating frequency

More power is required for higher frequencies

Data dispersion showed a non-uniform distribution

No external magnetic field applied: it would increase uniformity of burns and performance

Video



Interplanetary CubeSat missions

Attitude control and pointing are a key factor to achieve certain goals for any mission concept

µCAT supports various potential applications at low complexity and cost

Examples:

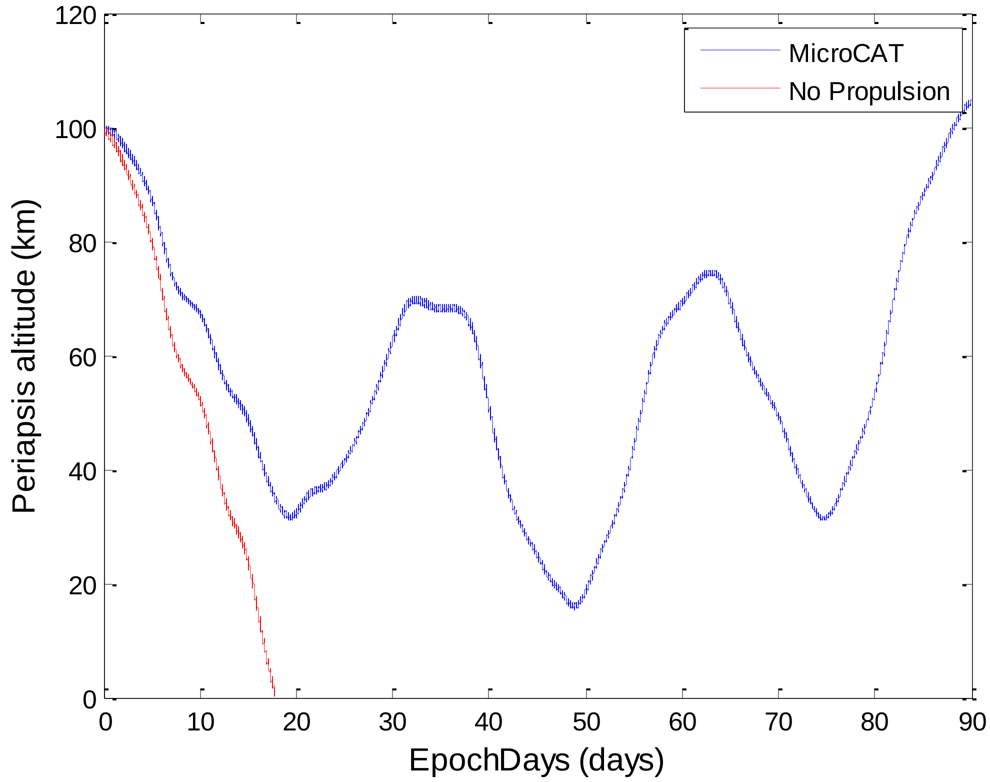
- Communication requirements (point at Earth to Deep Space Network)
- Science requirements
- Fine pointing
- Reaction wheel desaturation
- Small correction maneuvers and station-keeping applications
- De-orbiting for End-of-Life requirements

Set the ground for electric propulsion technology demonstration in CubeSats

Create a standardization for thrust stand measurements that can be comparable

Example: Lunar orbit maintenance

- LP150Q Lunar gravity model
- 100 km initial altitude circular orbit
- 15 degrees of inclination
- Assumption of 15 μN continuous thrust
- Thrust direction along the velocity vector



Conclusions

- NASA Ames – GWU micro-propulsion system is nearly ready to perform a flight demonstration mission
- Thrust stand results have proven system functionality
- µCAT provides an easy and simple interface at low production and development cost
- Performance can be adapted to various mission constraints: power, thrust, propellant mass (ΔV)
- Interplanetary CubeSats will benefit from µCAT due to its low power, mass and complexity requirements

Thank you for your attention

Members and collaborators

NASA Ames	The George Washington University	NASA Glenn Research Center
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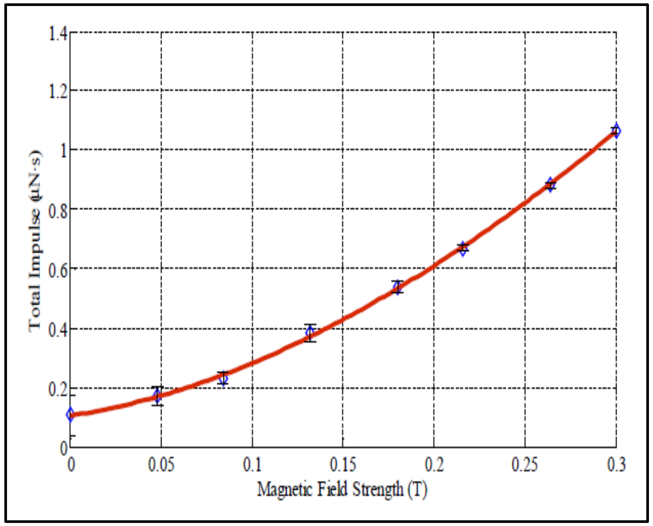
Backup slides

µCAT thruster testing

University of Southern California test

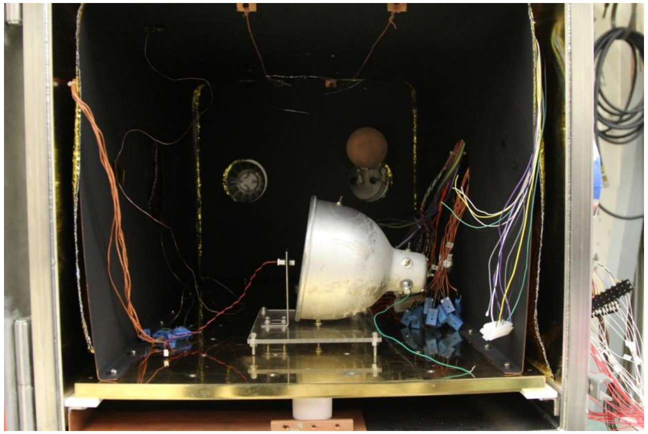
- Thrust measurement with a torsional thrust stand mass balance
- 14 impulses fired at 50Hz to get the best measurement (10% of the thrust stand period)
- Impulse bit measured without magnetic field 7.2±0.2e-7Ns
- Impulse bit reaches 1.1e-6Ns with 0.3T magnetic field
- Thrust to power ratio: 7.2µN/W



Performance characterization of Micro-Cathode Arc Thruster, AIAA 2011

NASA Ames Research Center Test - 2013

- Functional test of the system commanded by a smartphone
- 3 different channels
- Frequencies tested: 1-10Hz
- Vacuum test performed at NASA ARC Engineering Evaluation Laboratory. Continuous operation of 2 hours



The PhoneSat-EDSN bus

PhoneSat-EDSN subsystems:

CnDH

- Nexus S smartphone
- Serial Router

EPS

Communication

- MHX radio for Ground Operations
- **Lithium radio for crosslinks**
- StenSat beacon

ADCS

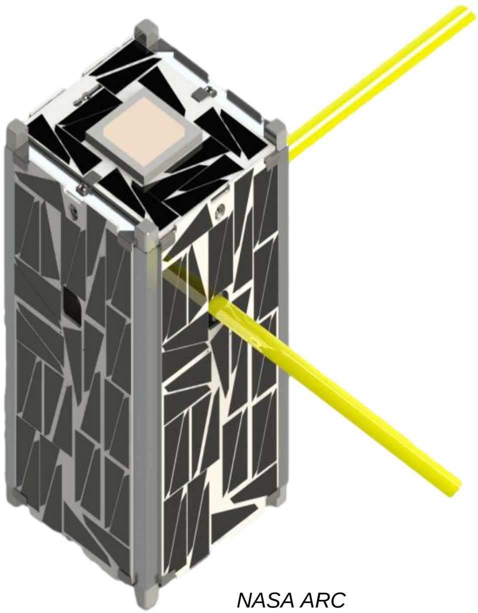
- Reaction Wheels
- Magnetorquers

Power

- Solar panels
- Li-Ion batteries

GPS

Payload



NASA ARC

Flights:

PhoneSat 1.0: 2 units, April 2013

PhoneSat 2.0: 4 units: April & November 2013, April 2014 (x2)

EDSN: 8 units, TBD

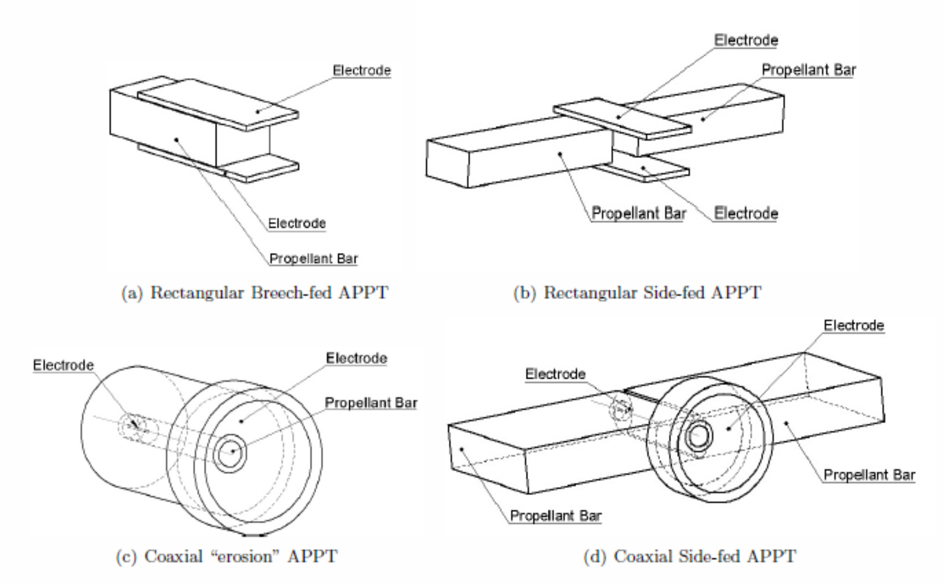
NODeS: 2 units, TBD

Micro-pulsed plasma thrusters

State of the art: need to efficiently convert from laboratory prototypes to robust spacecraft subsystems

PPTs:

- Ablate solid propellant between 2 electrodes
- Carbonization of the polymer propellant decrease lifetime
- Contamination may affect other components
- Low efficiency due to the creation of low speed vapor after the main discharge
- High breakdown voltage (>1kV) required in some cases



PPT thruster head electrode configurations (Gessini et al., 2013)