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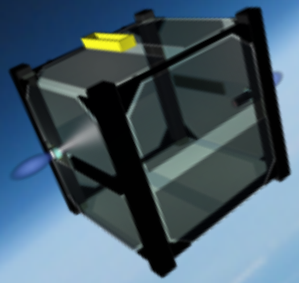


Agile development process of flight hardware for a quad-channel Micro-Cathode Arc Thruster (μCAT) subsystem for the 1.5U BRICSat-P cubesat missions.

Samudra Haque, Ph.D Candidate
Department of Mechanical and Aerospace Engineering

My focus areas …

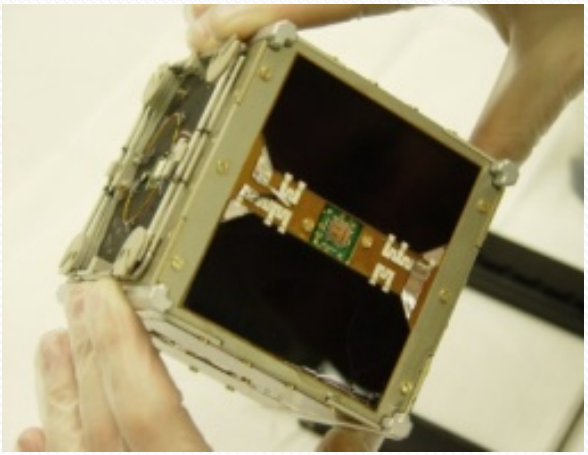
Samudra E. Haque
N3RDX

- **PhD Candidate, Aerospace Engineering, 2014 (GWU)**
  - Scalable Small Spacecraft Micropropulsion subsystems
  - Investigation of small spacecraft contamination possibility due to the use of closely located plasma thrusters
  - Linear-Circular Commutating Chain multi-hop comm relay networks
- Admin Contact: On-orbit Micropropulsion eXperiment Program
- MS in Space Studies w/Honors (AMU/APUS)
- Secretary, IEEE-AESS Aerospace Systems Integration Engineering Panel
- Currently Affiliated with NASA ARISS, AMSAT, AMRAD, ARRL
- Former MD & CTO of an WAN and VSAT Satellite Operator (’91-’05)

Small Satellite Micropropulsion era "officially" has begun …

CDS 13 (2014): ".. Removed restrictions on propulsion, added guidance for propulsion systems.."

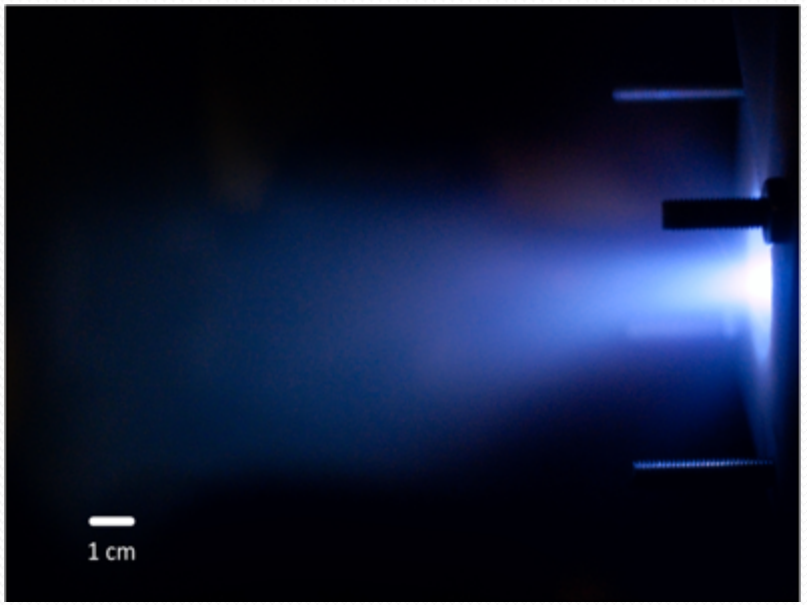
- CDS standard discusses qualification procedures for CubeSat developers who include liquid, semi-liquid, gas based systems.
- Electric propulsion is a safe alternative, but upto present date, solutions have not been readily available to fit small satellites bus structures (1U ~ 6U) that would allow combinations of the needs outlined in order of complexity →



Complexity	Application
Low	Station Keeping (SK)
	Orbit Maintenance (OM)
	Orbit Adjustment (OA)
Medium	Attitude Control (AC)
	Orbit Transfer (OT)
	In-Space Propulsion (ISP)
	Deorbit System (DS)
High	Proximity Operations

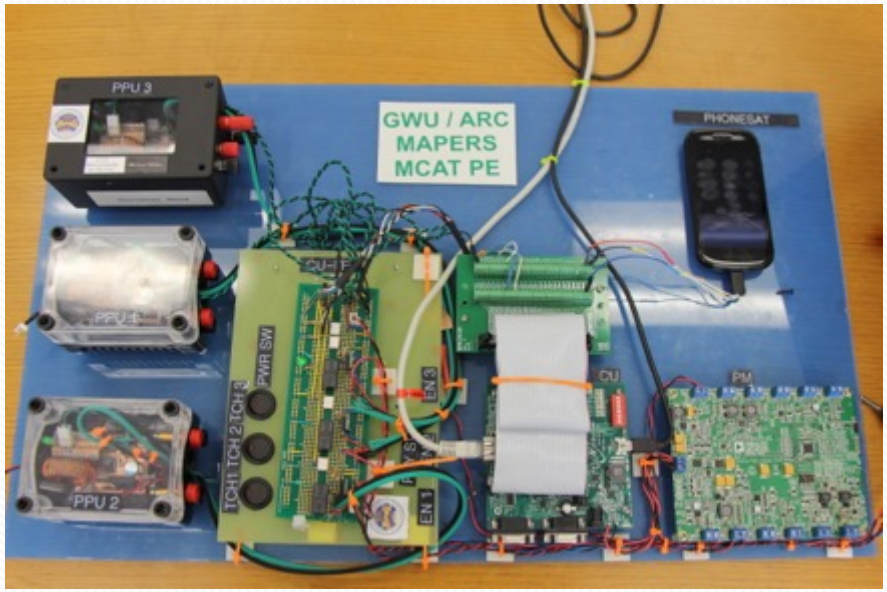
µCAT Thrusters a number of needs … in the area of SSM

- Provides electric propulsion capability for “SmallSats” of upto 50 Kg … starting from ~0.5U for 4-channels.
- Subsystem designed specifically to be an electric propulsion system that is…
  - Low-cost
  - Reliable and simple
  - Power efficient
  - Scalable and modular
  - Safe for the satellite and launch vehicle
  - Low contamination Risk



The Innovation and Advantages

- The cathode is the propellant
- Extended lifetime
- Reduced system mass/volume and power efficient
- Low voltage
- Zero contamination effect
- Easy to integrate
- Precision synchronized control of multiple channels

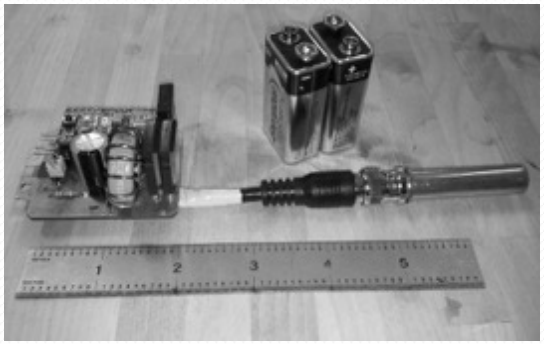


TRL5 achieved at NASA ARC EEL (August 2013) with 3-channel µCAT subsystem testing with PhoneSat SmartPhone CPU

(It's h-u-g-e … and we are reducing this to CubeSat PCB sizes with addl functionality)

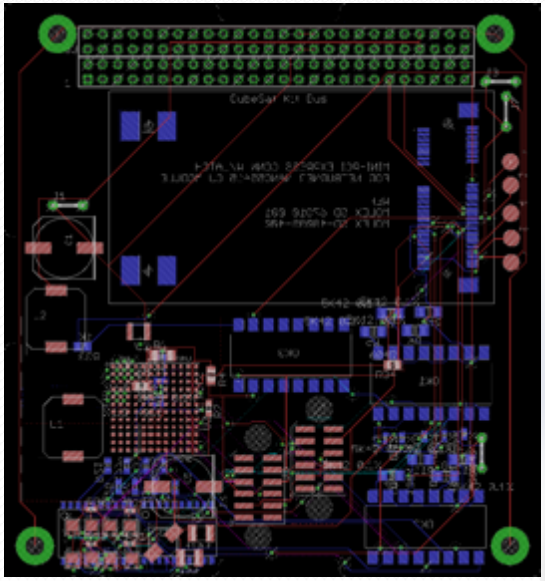
Rapid development requirement is .. very challenging and interdisciplinary in nature …

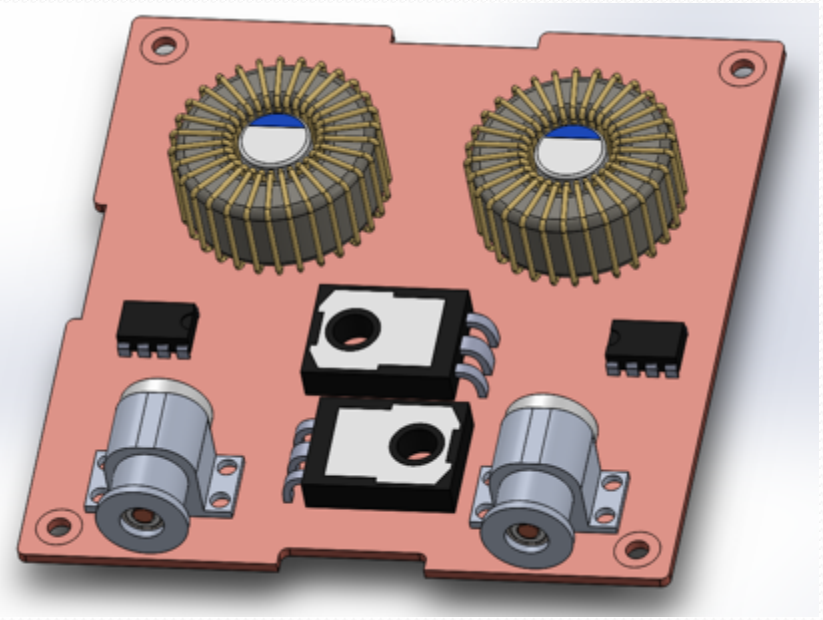
2012



2013

2014





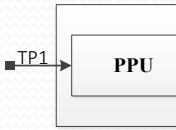
3..2..1.. Launch!

2015

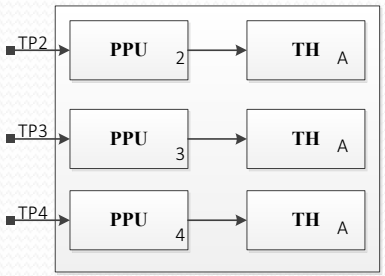
Challenges > Research Scope

- Scalable configurations
  - Included: Single Channel and Array
  - Excluded: Cluster, Hybrid

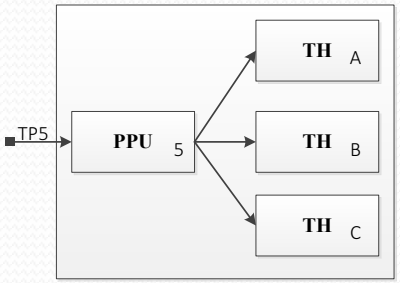
Thruster geometry
(finalized 8/2013)



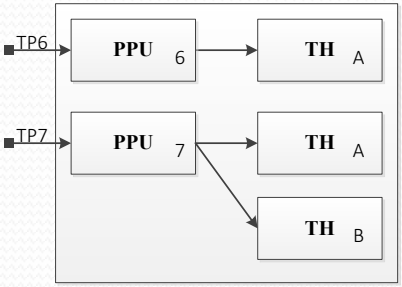
single channel



array



cluster



hybrid

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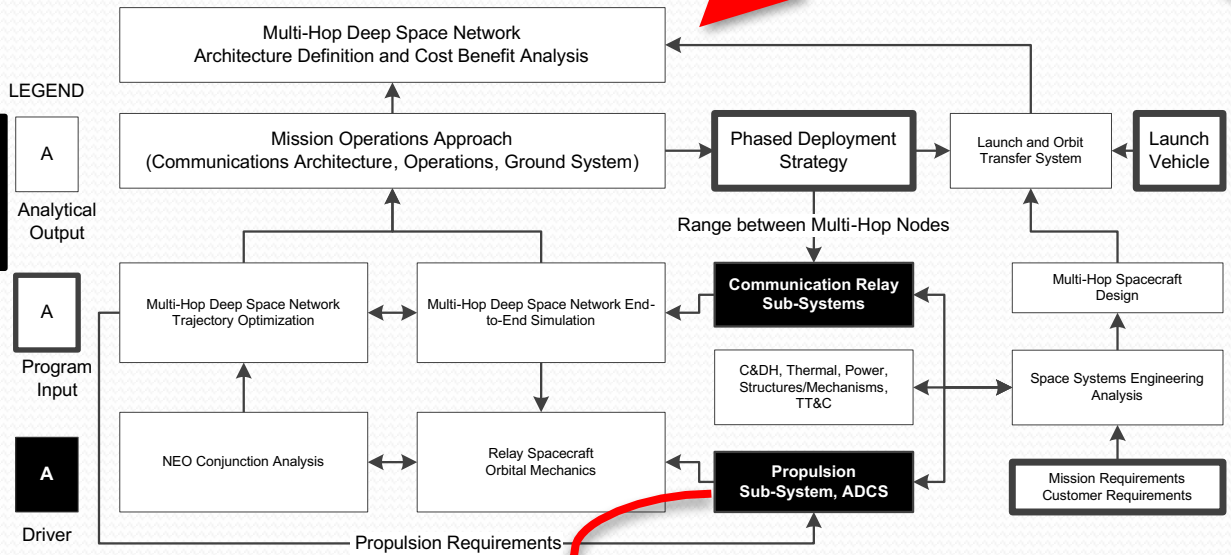
Challenges > Motivation

2009



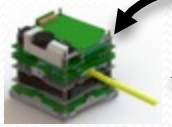
Small spacecraft contamination study will help qualify EP plasma systems for broader use in space missions

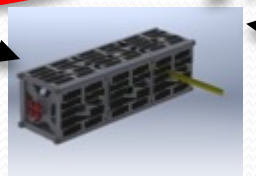
Typical plasma thruster applications

2010

Complexity	Application
Low	Station Keeping
	Orbit Maintenance
	Orbit Adjustment
Medium	Attitude Control
	Orbit Transfer
	In-Space Propulsion
	Deorbit System
High	Proximity Operations

2013



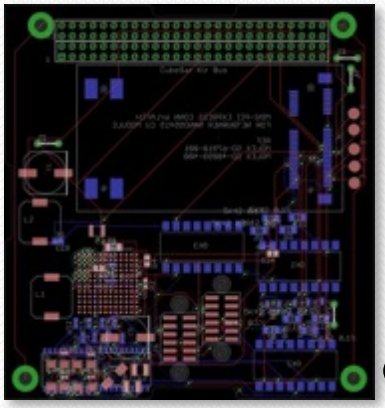


Example Technical Approach (Contamination Studies)

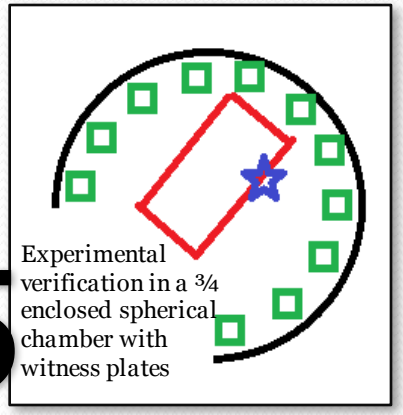
- Theoretical Model and Simulation
  - Rapid plasma plume investigation
    - Identify appropriate base reference model
    - Adapt computer application
      - Multi-scale analytical methods [1]
      - Coarse method using selective regions (not all of spacecraft) or SPIS [2]
      - Assume gaps in analytical coverage, to be replaced with direct 'circuits' between known locations
- Experimental verification
  - Verify using witness plates
  - ¾ Hemisphere placement
  - Utilizing 4-channel controller at MpNL
    - Already designed 2011-2014 by current student
  - Multiple mode operation
    - Unitary
    - Array
    - Selected set operation
- Correlation check between modeling/simulation and in-situ experiment
- Data Analysis

[1] Dissertation - Multiscale Modeling of Hall Thrusters. Lubos Brieda. 2012
[2] Dissertation - Modelling of plasma thruster plumes for spacecraft plume-impingement analysis. Nuno Jo~ao Machado Loureiro. 2010.

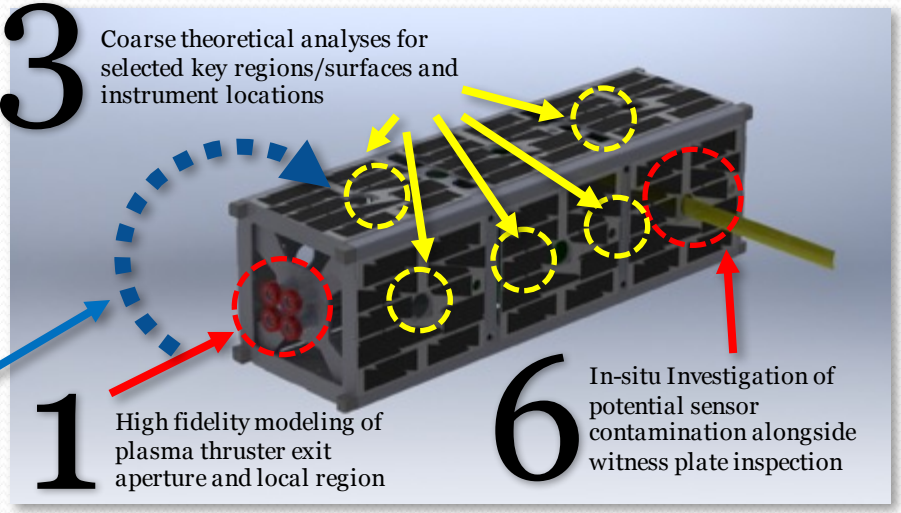
4 Variation of impulse-bit generation method under software control



5 Experimental verification in a ¾ enclosed spherical chamber with witness plates



3 Coarse theoretical analyses for selected key regions/surfaces and instrument locations



2 Mathematical "assumption" that direct circuit/contamination pathway exists to enable rapid plasma plume/spacecraft configuration investigation and plasma plume-plasma plume modeling

1 High fidelity modeling of plasma thruster exit aperture and local region

6 In-situ Investigation of potential sensor contamination alongside witness plate inspection

MpNL seeks joint research partners … to expedite the systems engineering processes and to get early feedback on the design …

OMXP

On-orbit Micro-propulsion Experiment Program

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- A 5-year program offering MpNL Micro-propulsion products to institutions
- US and International institutions welcome, as Joint Research Partners.
  - International institutions may be subject to US Govt. approval
- Goal of this program is to obtain in-space test and performance data from subsystems prepared for a space mission, provided to spacecraft bus developer, and flown into space as an integral part of that mission concept, with cost recovery.
- Started 1st March 2014
- Announced at 2014 IEEE Aerospace Conference, Big Sky, MT

OMXP

On-orbit Micro-propulsion Experiment Program

Program Director	Program Coordinator
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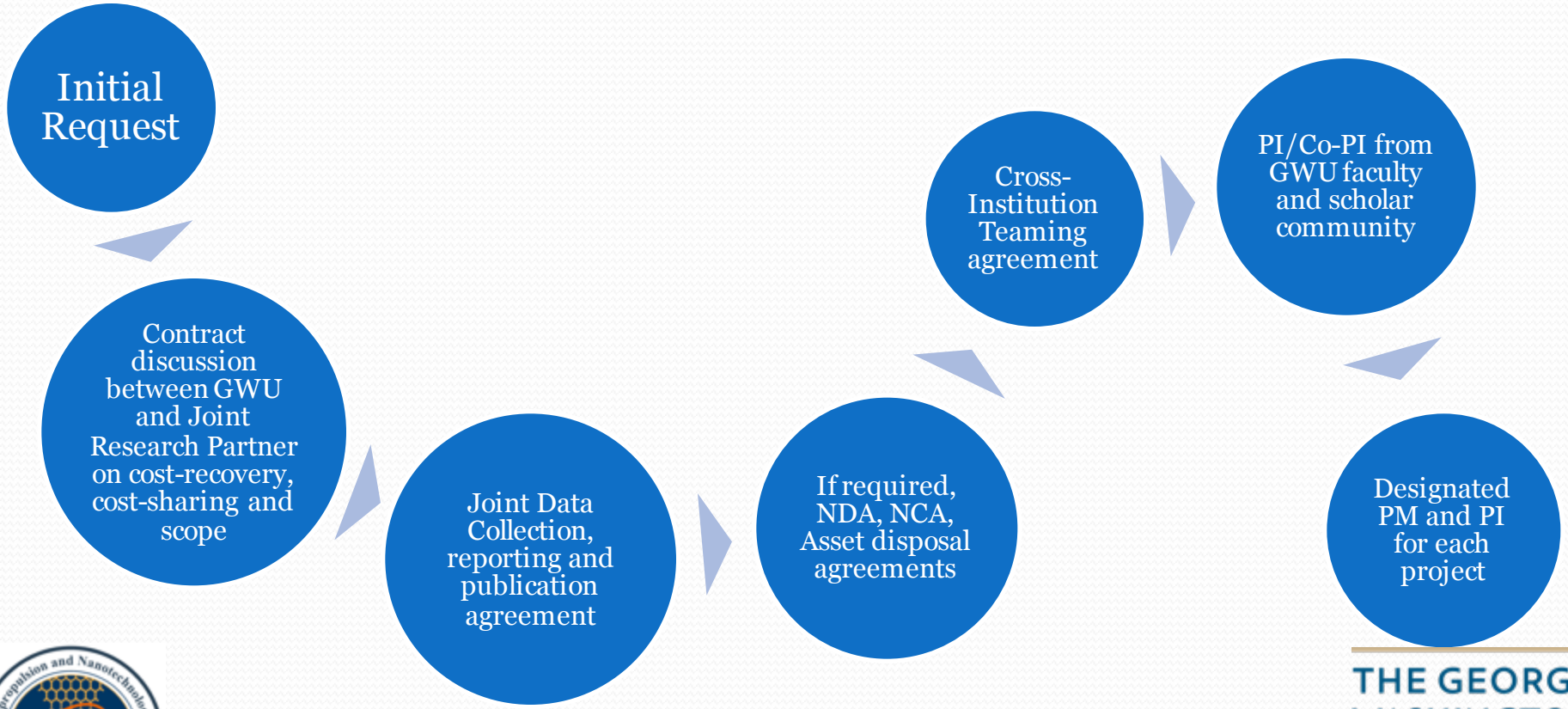

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MPNL
The George Washington University

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Research > Accelerated and Agile µCAT development program

- All processes simultaneously from Feb-June ’14 at GWU:
  - Breadboard tests using COTS parts modules under various working groups
  - Modeling/Simulation using standard tools and software throughout program
  - Manual and Automated verification of Schematic and Board designs, with reference to sample hardware from vendors; Legacy software porting
  - Test hardware units to USNA from GWU to impart familiarity with micro-thruster operation in vacuum and fit check (also virtual CAD models)
  - Engineering Models
    - Engineering Model-1, as full-up system, inclusive of Controller PCB, Thruster PCB, Thruster Heads
      - Complicated by student workload, and graduation plans of senior classmen
      - Additionally complicated by new class of technology in the CubeSat industry (for 2014)
      - After test and debut program to be repurposed as Flight Candidate #1
      - Will spawn Engineering Model-2
    - Engineering Model-2 (May 2014)
      - Only debug process allowed; Design freeze required
      - To be converted to Flight Candidate #1
  - Spare manufacturing assemblies for Engineering Models in case of any h/w failure

Conclusions

- OMXP program has been established at GWU to facilitate experiments with micro-propulsion by any academic institution, and to expedite the maturation of its system engineering process requirements.
- µCAT subsystems able to perform between 1-50 Hz are recommended for initial space missions.
- A process has been adopted to rapidly develop micro-propulsion system according to requirement, and to quickly validate and implement a design.
  - simultaneous,
  - inter-disciplinary
  - multi-site development
- First design to be flight qualified is expected to be less efficient and is for first on-orbit demo purposes only.

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Acknowledgements …

•Micro-cathode arc thruster physics a

•Total: $0.5M funding

•Validated thruster technol

•3 Patents (pending)

Questions?

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