Using Additive Manufacturing to Print a CubeSat Propulsion System

William M. Marshall
NASA Glenn Research Center

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Co-authors:

- Michael Zemba from NASA Glenn Research Center
- Corey Shemelya, Ryan Wicker, David Espalin and Eric MacDonald from University of Texas El Paso (UTEP) Wm. M. Keck Center for 3D Innovation
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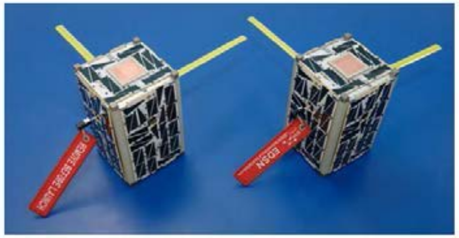
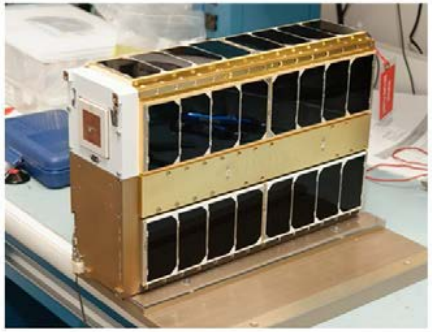
Introduction

- CubeSats are increasingly being utilized for missions traditionally ascribed to larger satellites
  - CubeSat unit (1U) defined as 10 cm x 10 cm x 11 cm
  - Have been built up to 6U sizes
- CubeSats are typically built up from commercially available off-the-shelf components, but have limited capabilities
- By using additive manufacturing, mission specific capabilities (such as propulsion), can be built into a system
- This effort is part of NASA STMD Small Satellite program “Printing the Complete CubeSat”



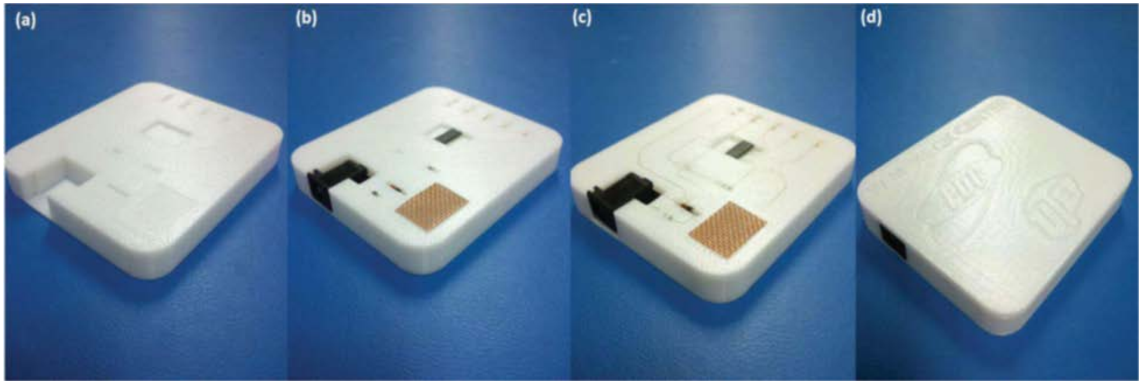


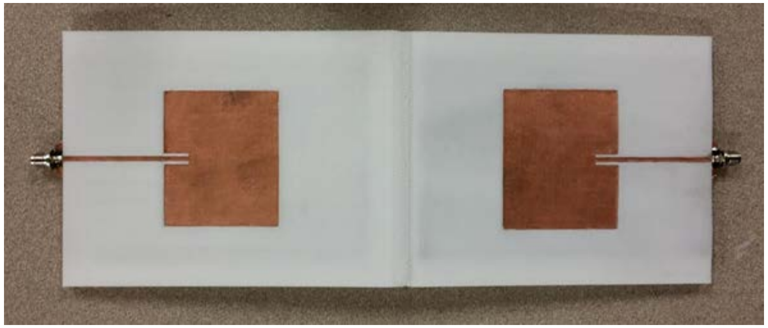
Additive Manufacturing - Background

- Additive Manufacturing (AM), or 3-D printing, is a manufacturing technique where material is added to create a part layer-by-layer
- Various techniques are available in both plastics and metals, including materials extrusion, direct laser metal sintering (DLMS), and selective laser sintering (SLS)
- Materials extrusion is becoming prolific as “art-to-part” desktop systems become more common
  - In materials extrusion, a print head extrudes thermoplastic in a fine thread of material. The print head follows a programmed path, laying down material, to create the layer. As the layer is completed, the build table drops so the next layer can be built.

Additive Manufacturing – Embedding Electronics

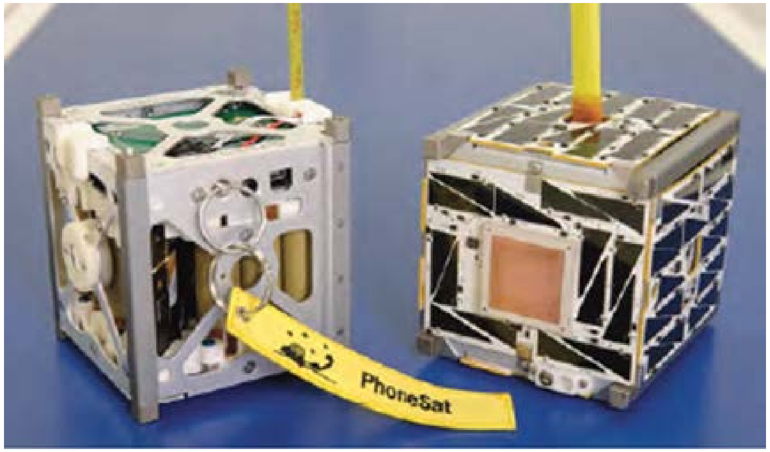
- The University of Texas El Paso (UTEP) has developed the ability to incorporate electronic components and sensors directly into the materials extrusion process
  - This includes the ability to embed fully dense copper wire or mesh into a part
    - Conductive inks are limited in conductivity when sintered below 550 °C
    - For polymer 3D parts, sintering temperatures must be confined to deflection temperature of parts (~280 °C for polycarbonate)
  - Allows for inclusion of electrical systems & antennas to be incorporated into structure

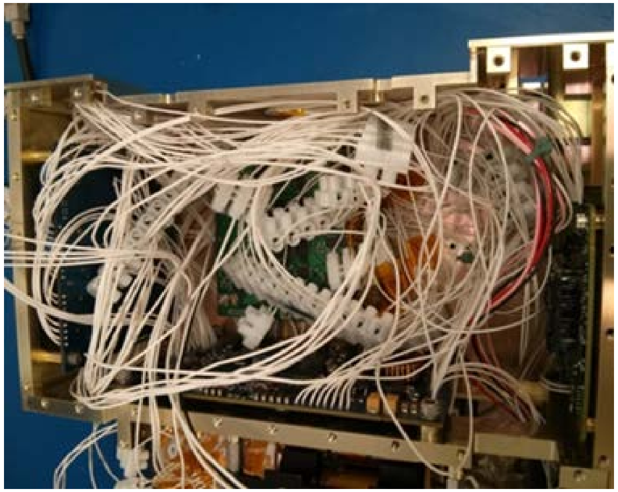




Application to Spacecraft

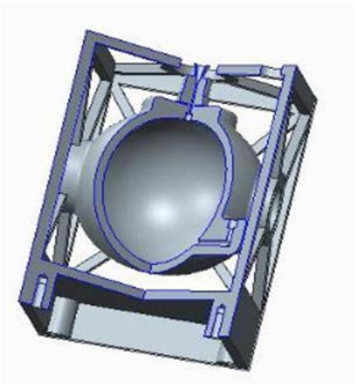
- CubeSats are mass and volume constrained
  - Starts with a commercially available “frame” or bus into which components are placed
  - More complex spacecraft create packaging difficulty
- Embedding wiring/electronics into structure saves internal volume for other components
- Current effort is investigating the use of AM for embedding antennas and propulsion systems

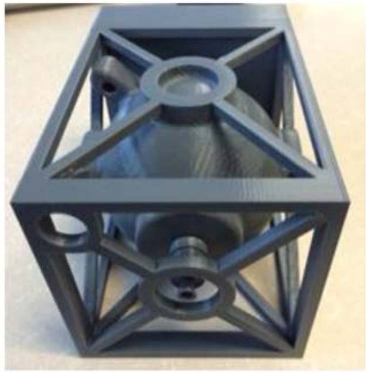




Propulsion Concepts

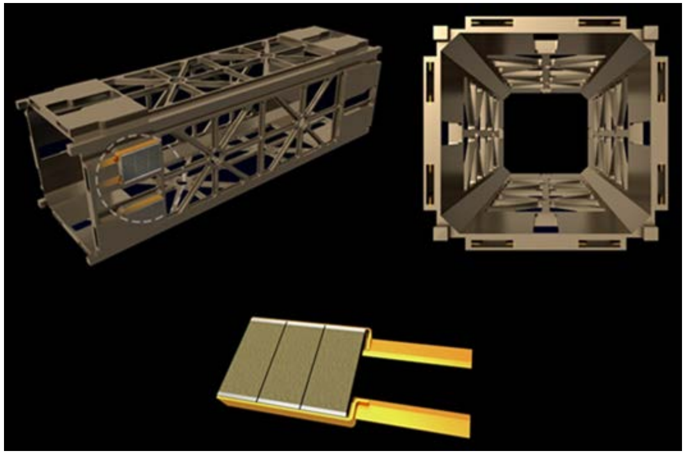
- Interest in propulsion concepts for CubeSats is rapidly gaining interest
  - Numerous concepts exist for CubeSat scale propulsion concepts
  - The focus of this effort is how to incorporate into structure using additive manufacturing
- End-use of propulsion system dictates which type of system to develop
  - Pulse-mode RCS would require different system than a delta-V orbital maneuvering system
  - Team chose an RCS system based on available propulsion systems and feasibility of printing using a materials extrusion process
- Initially investigated a cold-gas propulsion system for RCS applications
  - Materials extrusion process did not permit adequate sealing of part to make this a functional approach

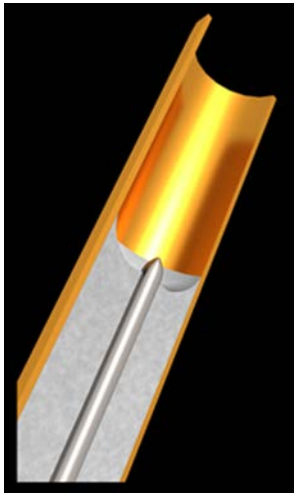




Propulsion Concepts (cont.)

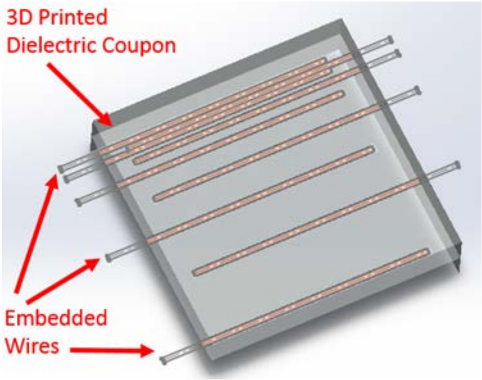
- Micro Pulsed Plasma Thrusters (μPPT) identified as alternative approach
  - Can be tightly packaged
  - Supporting structure can be easily printed and electronics embedded
  - Sufficient propulsive capabilities for RCS
- Two main types of μPPT exist
  - "Surrey" design
  - Coaxial
- Availability of coaxial type led to use in this effort





Preliminary Results – Dielectric Testing

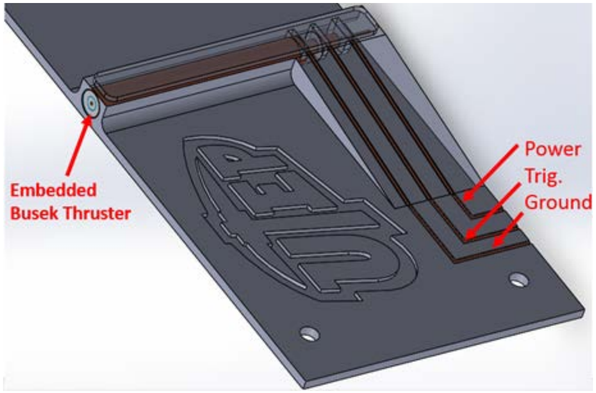
- Since μPPTs require high voltage (~1.5 kV) across electrodes to operate, understanding dielectric strength of printed material is critical
  - Some reduction in the dielectric strength of the material is expected due to porosity
- Sample coupons with wires embedded allowed for testing of dielectric strength of material
  - Printed with T16 tips (254 μm of raster separation), 28-AWG bulk copper, in polycarbonate
  - Wires were oriented at ±45° relative to raster direction
- Expected dielectric strength of raw material was 80 V/mil
- Testing was conducted at two different wire separations up to 10kV (limit of tester)
  - Voltage applied between parallel wires, and resistance measured
- Although dielectric strength was lower than published, this was expected and well above the required voltage to run μPPTs
- Future testing would examine impact of raster angle, material, and other wire separation distances



Wire Separation	Resistance at 5 kV	Breakdown	Expected Breakdown
4.76 mm (0.1875 in.)	25.1 GΩ	7.5-10 kV	15 kV
9.53 mm (0.375 in.)	22.8 GΩ	>10 kV	30 kV

Preliminary Results – Thruster Firing Tests

- Proof-of-concept tests were conducted to embed a μPPT into a polycarbonate sample body
- Sample panel was printed, μPPT embedded, wires placed, and sealed with further printing over μPPT
- Ramp feature allowed for routing of wires from thruster down body to connections

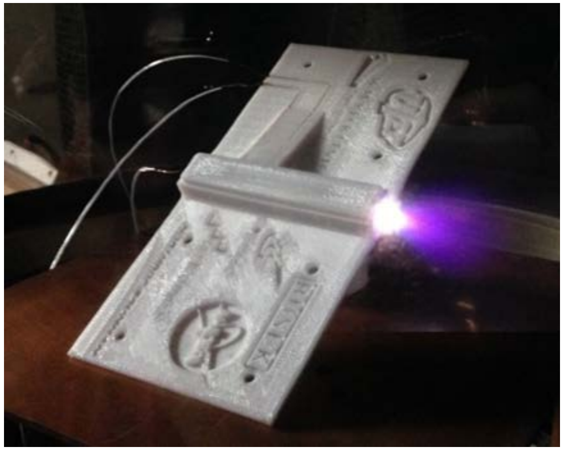


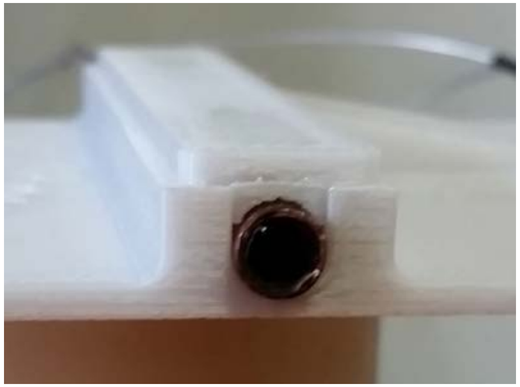
(A.)

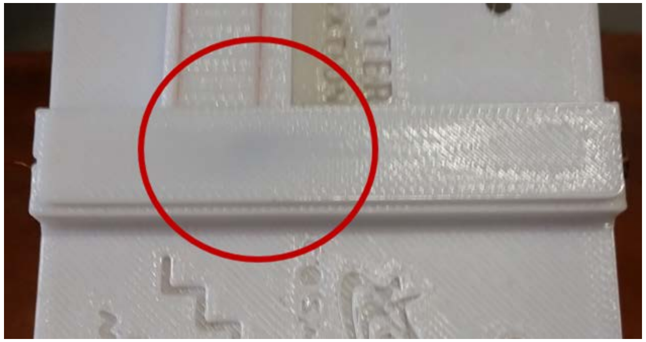

(B.)

Preliminary Results – Thruster Firing Tests

- Tests were conducted at Busek in vacuum (~10^{-5} torr)
- Operated at 800-1500 V, 2 J, 2Hz
- Limited data were collected, but photographs and video demonstrate thruster proof-of-concept operation
- No degradation of material near thruster exit was observed
- Some discoloration near wire junction observed – believed to be arcing between ground wire & copper sheath
  - Arcing did not prevent operation of the thruster
  - Future testing will determine cause of arcing and modify printing design as required
- Tests demonstrated μPPT could be embedded in a printed structure and still operate







Summary

- Additive manufacturing presents a unique opportunity to embed complex features and components into small satellite structures
- A micro pulsed plasma thruster (μPPT) was chosen for its characteristics and ability to allow embedding into a materials extrusion built part
- Initial dielectric testing shows an expected drop in dielectric strength of parts, but still sufficient for operating a μPPT
- Proof-of-concept thruster tests demonstrate that a μPPT can survive the printing/embedding process and can operate without significant degradation to surrounding material
- Demonstrates existing propulsion system designs can be incorporated into a CubeSat body, leading to possibility of one day printing a complete operational system

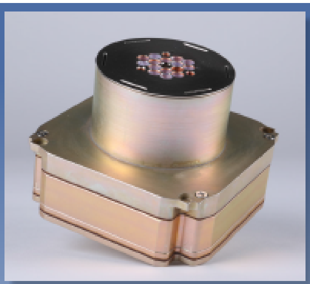
Backup

Busek BmP-220 μPPT

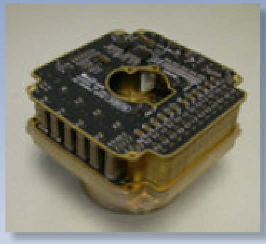
Busek's BmP-220 micro-pulsed plasma thruster is a small multi-thruster delivering 400 N-s/kg to CubeSats and micro-satellites. Novel, solid-state high voltage switching technology sources multiple emitters via a single self-contained power processing unit. The BmP-220 features long storage life and wide operational tempeature range with no moving parts, no pressure vessel, and non-toxic Teflon propellant, making it ideal for secondary payloads or international Space Station deployment. Busek's first generation pulsed plasma thruster, MPACS (Micro Propulsion Attitude Control System), successfully operated on FalconSat-3 (launched 2007).

Each unit contains all the necessary electronics (PPU/DCIU), requiring only power and command input from the host spacecraft.

- Predecessor design >7 years on-orbit aboard FalconSat-3
- Solid, non-toxic Teflon propellant
- No pressurized containers
- No moving parts
- Low power: <7.5W
- Precise, pulsed impulse bits (0.02 mN-s)



BmP-220
Micro Pulsed Plasma Thruster



BmP-220
Integrated PPU/DCIU

Busek Co. Inc specializes in providing complete electric space propulsion systems including but not limited to a wide range of thrusters, propellant management systems, power processing units and digital control interface units. Busek provides analytical, computational, experimental and product services to government and industry.

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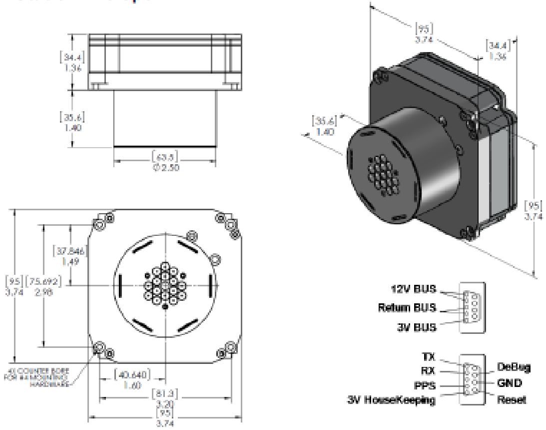
Static Envelope



System Power	1.5W (at 1 Hz) 7.5W (at 7 Hz)
Input Voltage	6-16 VDC (nominal 10V)
Interface	TTL
Mechanical	
System Mass	0.5 kg
System Volume	330 cm³
Propellant	PTFE (solid)
Performance	
Impulse Bit	0.02 mN-s
ISP	536 s
Total Impulse	220 N-s (40g propellant)
Heritage:	FalconSat-3, MPACS (first-generation mPPT) operational success