NASA MIRO University Research Center

# Center for Aerospace & Exploration Technology Research

The University of Texas at El Paso

## EMBEDDING ELECTROSPRAY THRUSTERS INTO CUBESAT RAILS

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# Electrospray Thrusters

Electrostatic propulsion systems with hundreds of micro-scale emitters in areas on the order of $cm^2$
- Low thrust, low impulse bit, high specific impulse
- Well suited for precision maneuvers and small spacecraft

Electrostatic forces extract and accelerate positive ions or droplets from an emitter tip
- Propellant surface deforms into cone-jet until electrostatic force overcomes surface tension

Electron source neutralizes the charged plume for spacecraft detachment and momentum transfer
*OR*
Alternatively, bipolar arrays alternate between emitting positive and negative ions to eliminate the neutralizer

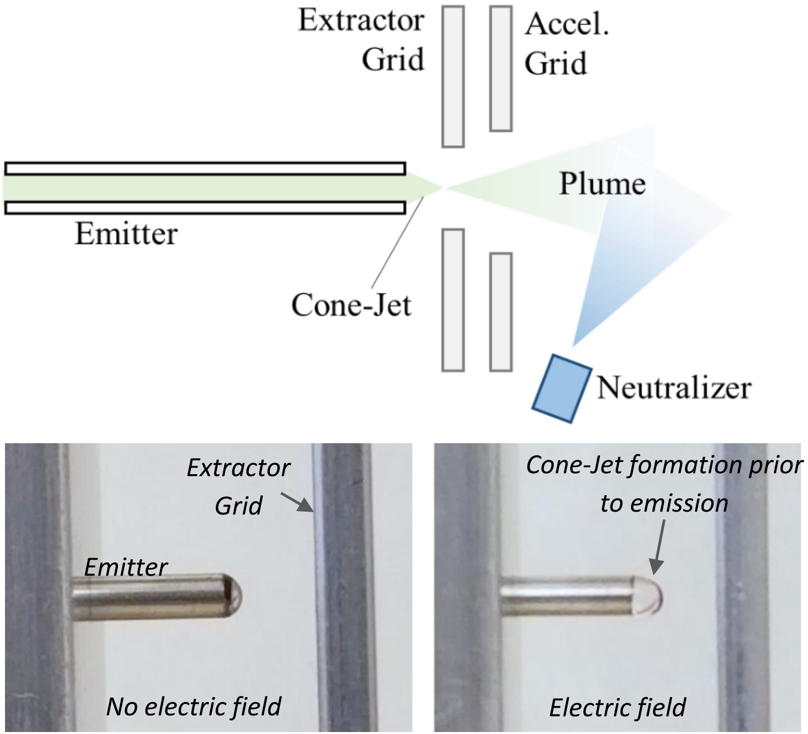



***Figure 1:*** *(Top) Standard Electrospray Configuration, (Bottom) Demonstration of cone-jet propellant emission*

# Electrospray Thruster Applications

Increased mission utility
- Orbit adjustments (altitude/phasing)
- Constellation formation
- Low thrust orbit transfer

Precision Control
- Precision attitude control (pointing)
- Formation flight maintenance
- Perturbation correction

Extended mission duration
- Drag compensation
- Perturbation compensation

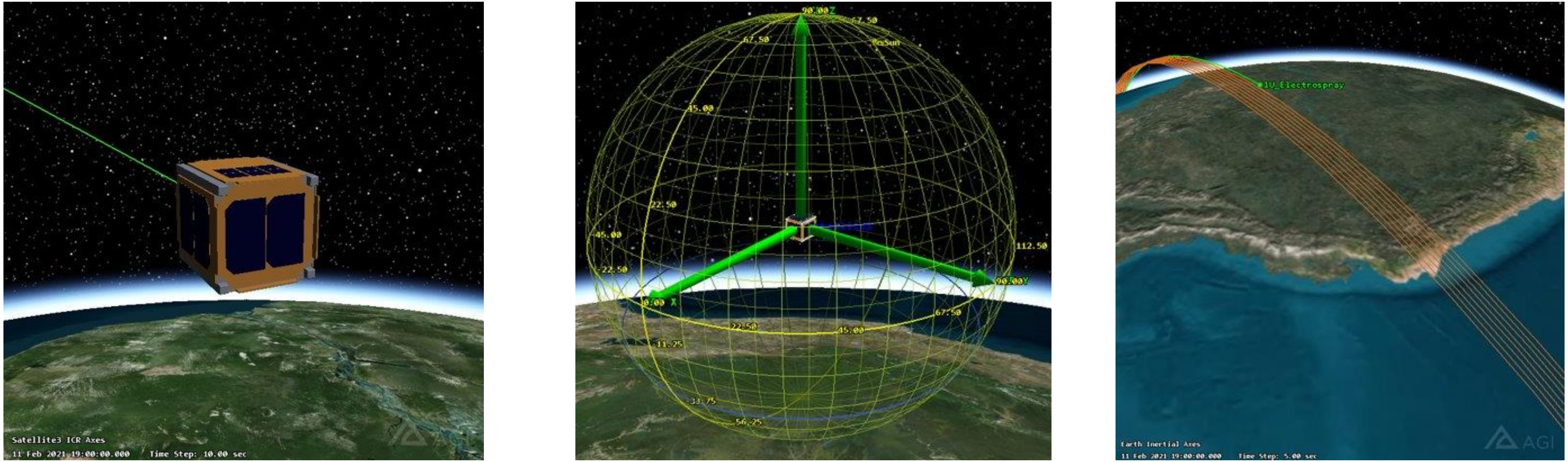



***Figure 2:*** *Left – Orbit transfer, Middle – Attitude control elements, Right – Drag compensation*

# Rail Thruster Concept

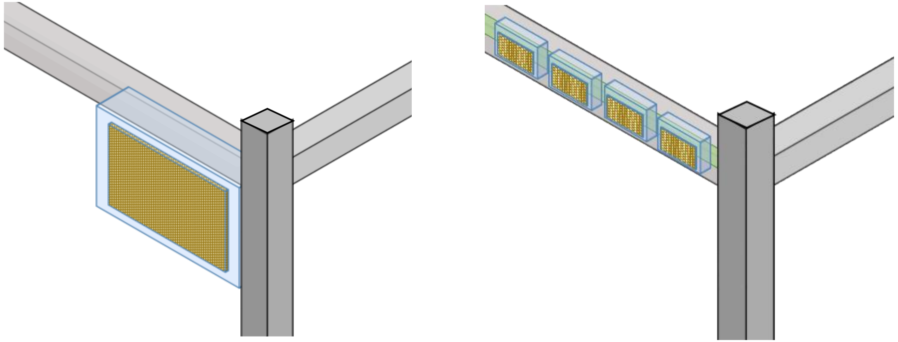


*Figure 3:* *Left - Traditional Thruster Integration (Representation) and Right – Rail Thruster Embedded Design (Representation)*

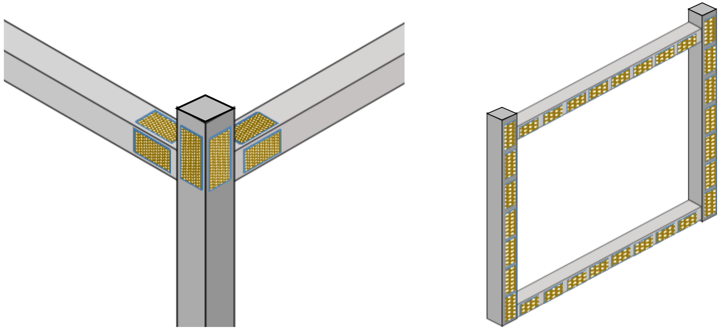


*Figure 4:* *Left – Orthogonal placement for 3-axis attitude control and Right – multiple arrays for increased linear thrust*

Commercial-off-the-shelf or plug-and-play electrospray thruster integration works for many missions

For missions needing increased utility without a size and weight penalty, embed electrospray thrusters into existing structural elements

Multiple rail thrusters embedded into a structure enables multi-maneuver capabilities

Modify thruster placement to suit mission requirements

- Orthogonal thruster arrays for 3-axis attitude control
- Multiple arrays on one face for increased linear thrust

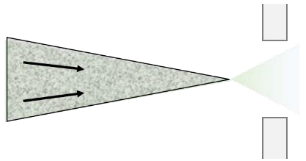
# Rail Thruster Prototype Design

Based around 8.5mm rail with 1mm chamfers as per CubeSat Design Specification Revision 13

Overall Geometry:
- 5mm wide, 5mm depth, 10mm length
- Single extractor grid, no accelerator grid
- 3D printed PLA rail segment *(prototype only)*

Propellant:
- EMI-BF4 (common electrospray propellant)

Emitters:
- Conical porous glass tips to avoid machining of microchannels
- 216 total emitters with ~200 micron feature size



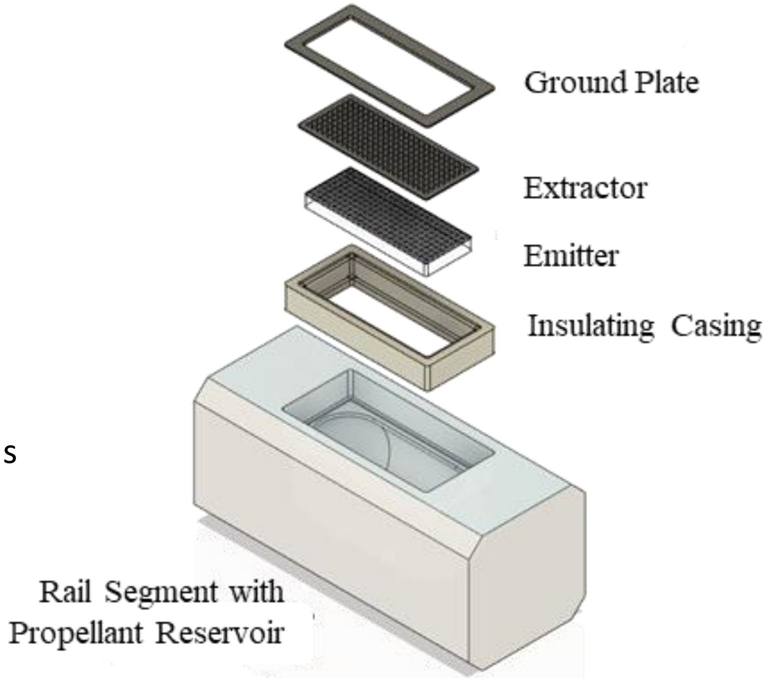



***Figure 5:*** *Rail thruster exploded view*

# Rail Thruster Electrical Connections

Electrical Properties:

- Extractor grid is electrically neutral with spacecraft structure
- Emitter array and propellant are biased relative to extractor
- Macor casing provides electrical isolation for emitters
- Plastic rail segment provides electrical isolation for propellant in prototype. For flight would need to revisit isolation design

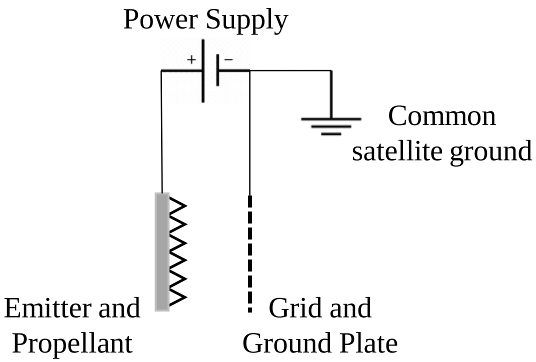



***Figure 6:** Rail thruster electrical diagram*

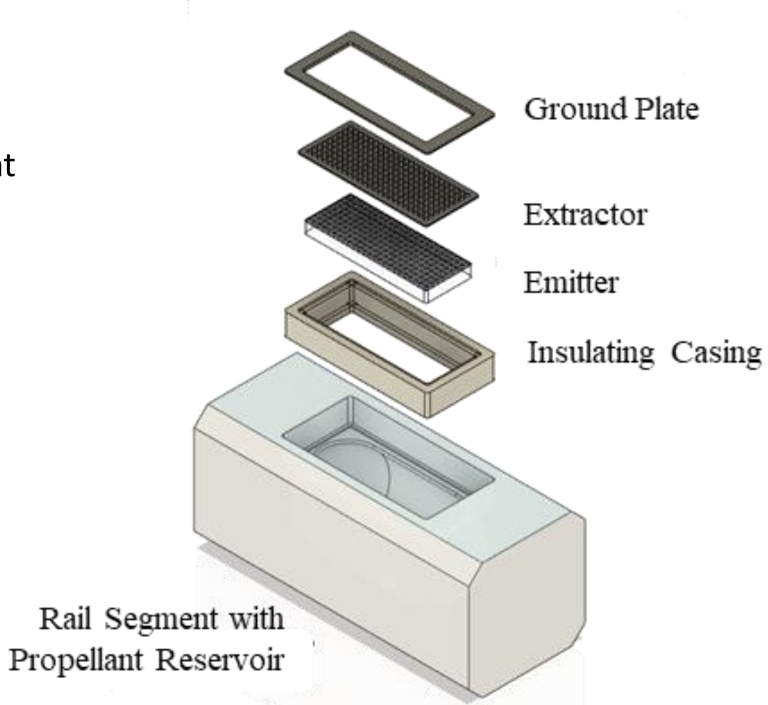



***Figure 5:** Rail thruster exploded view*

# Rail Thruster Manufacturing

Emitter Array:

- Borosilicate glass with 1–10 micron pores
- High precision CNC machine with a polycrystalline diamond cutter

Extractor Grid:

- Stainless steel 316
- Laser ablation
- Performed by a trainee to reduce costs leading to some imperfections

Macor Insulation:

- CNC machined
- Stepped design supports the relative stand-off distances

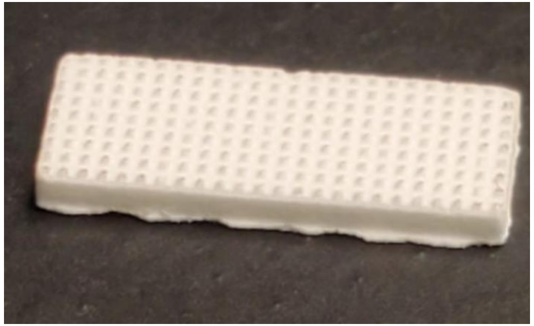


***Figure 7**: CNC Machined Emitter Array*

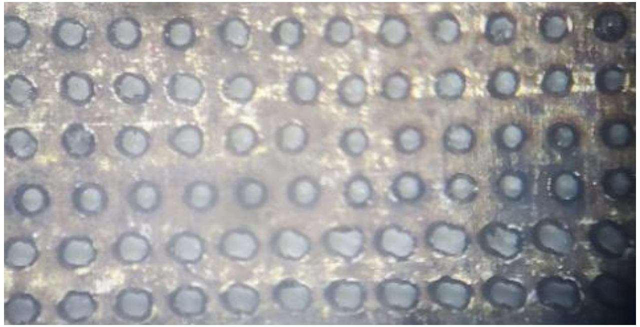


***Figure 8**: Imperfections in laser ablated holes*

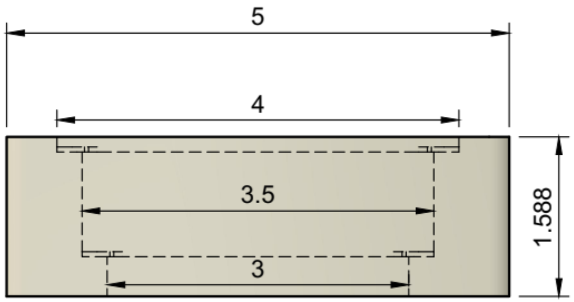



***Figure 9:** Stepped design of Macor casing*

# Rail Thruster Assembly

Vacuum-rated epoxy used to secure elements

- Prototype assembled by hand to minimize costs leading to some imperfections in alignment and spillages

Ground wires connected through soldering to outside of ground plate for prototype

- Does not sit flush with rail face. For flight designs, wires would be embedded inside the rail to prevent this

***Figure 10***: *Emitter in casing*

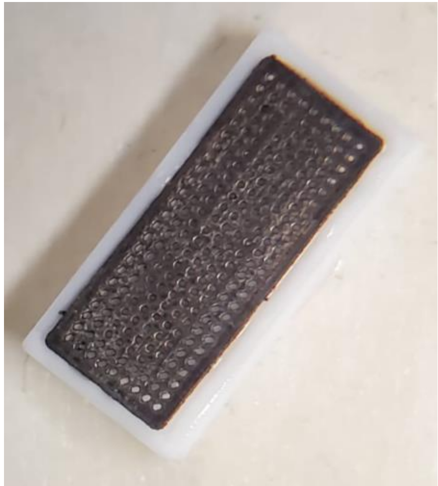


***Figure 11:*** *Assembled rail thruster*

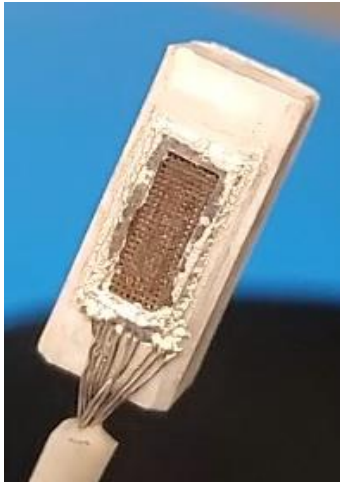


***Figure 12:*** *Embedded in rail*

# Rail Thruster Testing

Tested under vacuum in Plasma and Electric Propulsion Chamber (PEPC) at University of Texas at El Paso (UTEP)

- Picoammeter connected to a downstream collector plate detected thruster emission
- Applied thruster voltages swept from 500V to 1500V
- Increase in current with increase in voltage as expected
- Measured current is low – low tolerance manufacturing, imperfections in extractor grid, assembly by hand,

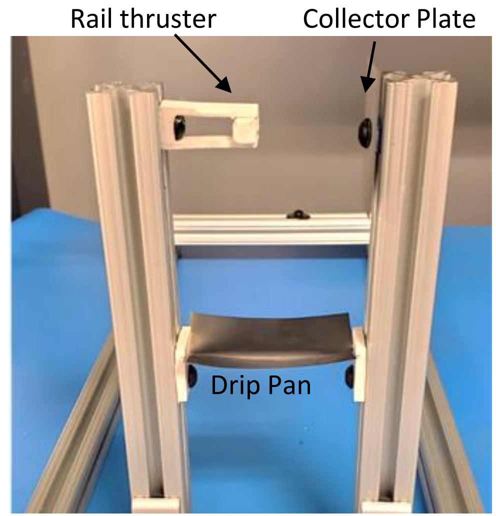



***Figure 13**: Rail thruster test stand*

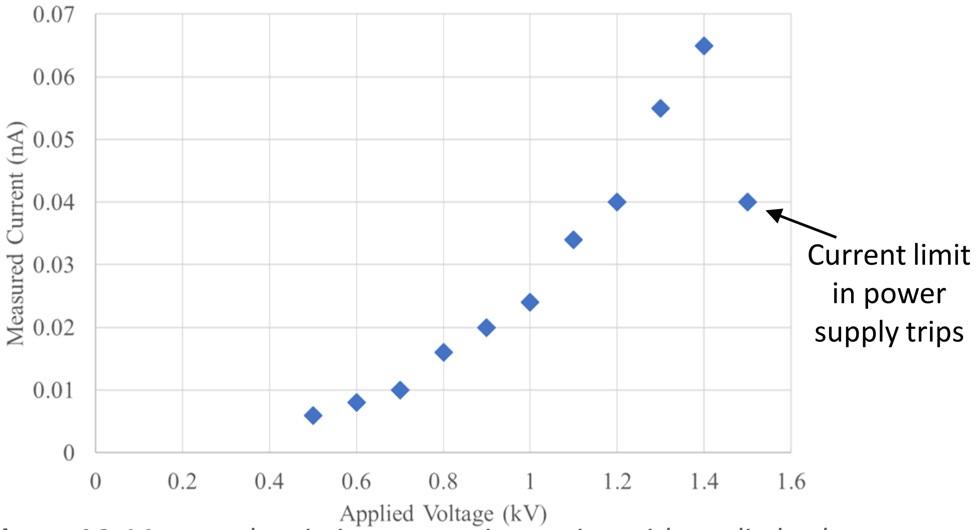



***Figure 14:** Measured emission current increasing with applied voltage*

# Rail Thruster Utility

Theoretical performance for each individual thruster array indicates specific impulse of 1600 s, a thrust of 2 micro-Newtons, and a delta-V of 5 m/s per rail thruster for a standard 1U CubeSat.

- *Not validated against prototype due to low quality manufacturing and imperfections.*

Mission Utility – *based on theoretical performance*

- 12 thrusters enables full 3-axis control with a total mission delta-V of 60 m/s
- 6 thrusters in each rail provides total linear thrust of 48 µN with a total mission delta-V of 360 m/s

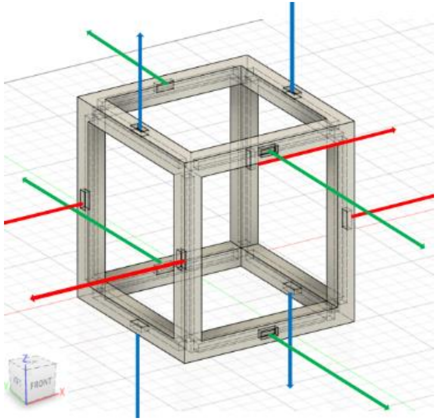


***Figure 15:*** *Rail thruster placement for 3-axis attitude control*

# Rail Thruster Summary

Initial prototype and testing results demonstrate the concept is feasible and warrant further development

- Design fits within a standard CubeSat rail including propellant
- Manufactured through common and low-cost techniques
- Emission detected during vacuum testing
- Versatile mission utility based on placement and quantity

The next steps in development are:

- Manufacture higher tolerance thruster (prototype 2)
- Eliminate wire protrusion and epoxy residue on rail face
- Directly measure thrust, specific impulse, impulse-bit, and efficiency under vacuum conditions
- Perform mission simulations to demonstrate practical utility

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***Figure 16:*** *Rail thruster on laptop keyboard for scale*