High Isp CubeSat Propulsion

Dr. Vlad Hruby
President
Busek Co. Inc.
Natick, MA

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Introduction

Satellites are becoming more capable due to willingness to accept less redundancy, miniaturization and MEMS devices – Moore’s Law and microfab techniques.

Impact is dramatic since much of a satellite is electronic parts, typically electronics is 30% of dry mass. This leads to smaller and smaller platforms with small loss of capability.

Two areas where miniaturization has not kept pace because of physics limits –
- optical (or RF) aperture size determines observation resolution and
- propulsion systems that are not easy to down size while preserving performance (surface-to-volume, very small nozzles, laminar flow losses etc). New approaches are needed (e.g. electrospray)

Busek will show seven CubeSat propulsion systems aimed at multiple missions using variety of approaches (electrothermal, electromagnetic, electrostatic, electrospray, green monoprops)
Nominal Thrust vs. Nominal Isp

Isp of EP devices is broadly adjustable, covers range from 150s to 4000s

- 1 green monoprop
- 2 ammonia resistojet
- 3 microPPT
- 4 passive electrospray
- 5 pressure fed electrospray
- 6 1cm RF ion
- 7 3cm RF ion

Line of constant power at 10W assuming 50% thruster efficiency
Busek CubeSat Propulsion Portfolio Summary

- **Electrospray Thruster**
  - High Efficiency
  - Multi-emitter
  - Low Risk / Technically Mature

- **Micro Pulsed Plasma Thruster**
  - No moving parts, valves
  - No pressure vessel
  - Low Power
  - Integrated Primary / ACS
  - Prior version flying on FalconSat3

- **Micro Resistojet**
  - Simple, ideal for prox-ops
  - Higher thrust (scales with power)
  - Integrated Primary / ACS

- **1 cm Micro RF Ion Thruster**
  - No internal cathode
  - >2000s Isp
  - FE Neutralizer is space qualified

- **3 cm Micro RF Ion Thruster**
  - No internal cathode
  - Tested up to 3,000s Isp
  - Thermionic Neutralizer is space qualified

- **Green Monoprop**
  - High thrust (high Cubesat acceleration)
  - High density Isp
  - Low-toxicity propellant
Busek PUC Electrospray Thruster

**PUC Electrospray Thruster**

- Low Risk
  - leverages $20M NASA ST7 Technology flight development
  - Leverages SBIR work on micro-valves and power management
  - Phase I risk reduction successfully completed
- 151 m/s \( \Delta V \) for 4.0kg spacecraft
- Safe, Non-Toxic, Non-Volatile Propellant
- Up to 1mN thrust output
- 452 hours of life in Busek’s lab
- ICD, all Manufacturing Drawings completed

**Remaining Development to Flight**

- Package Design of the PPU
- Construct
- Shock / Vibe / Thermal cycle

**Key Performance Characteristics, Busek PUC Electrospray Thruster**

<table>
<thead>
<tr>
<th>System Volume</th>
<th>0.5 U</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Mass</td>
<td>&lt; 1.15 kg</td>
</tr>
<tr>
<td>System Power</td>
<td>&lt; 9 W</td>
</tr>
<tr>
<td>Thrust</td>
<td>0.70 mN (range 0.1 – 1.0 mN)</td>
</tr>
<tr>
<td>ISP</td>
<td>800 s (range 625 - 1,300 s)</td>
</tr>
<tr>
<td>Delta V</td>
<td>151 m/s</td>
</tr>
<tr>
<td>(for 4kg spacecraft)</td>
<td></td>
</tr>
<tr>
<td>TRL</td>
<td>5</td>
</tr>
</tbody>
</table>
Busek HARPS Thruster

HARPS Thruster
✓ Leverages NASA ST7 Technology flight development
✓ Life limiting elements well known
✓ Modular
✓ Phase II under development
✓ Safe, Non-Toxic, Non-Volatile Propellant
✓ Features Low Power operation (~0.57W)

Remaining Development to Flight
✓ Package Design of the PPU
✓ Construct
✓ Shock / Vibe / Thermal cycle

Thruster including fuel storage, PPU not shown

Key Performance Characteristics, Busek HARPS Thruster

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Volume</td>
<td>&lt; 0.4 U</td>
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<tr>
<td>System Mass</td>
<td>&lt; 0.4 kg</td>
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<tr>
<td>System Power</td>
<td>&lt; 1 W</td>
</tr>
<tr>
<td>Thrust</td>
<td>0.1 mN</td>
</tr>
<tr>
<td>ISP</td>
<td>750 s</td>
</tr>
<tr>
<td>Delta V (for 4kg spacecraft)</td>
<td>76 m/s</td>
</tr>
<tr>
<td>TRL</td>
<td>3-4</td>
</tr>
</tbody>
</table>
Busek 1cm RF Ion Thruster

Micro RF Ion Thruster
- Low Risk
  - Leverages NASA ST7 Technology flight development (cathode, valves)
  - Leverages NASA SBIR funding on a 400W RF ion thruster development
  - Leverages SBIR work on micro-valves and power management
- Phase II risk reduction successfully completed
- ICD Complete
- Innovative, patent-pending micro RF power generator
- Up to 150µN thrust and 4000sec Isp output

Remaining Development to Flight
- Additional performance point optimization
- Additional performance characterization
- Miniaturization of Electronics
- Package Design of the PPU and RF power generator
- Construct
- Shock / Vibe / Thermal cycle

Key Performance Characteristics, Busek RF Ion Thruster

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Volume</td>
<td>&lt; 1.25 U</td>
</tr>
<tr>
<td>System Mass</td>
<td>~ 1.25 kg</td>
</tr>
<tr>
<td>System Power</td>
<td>10 W</td>
</tr>
<tr>
<td>Thrust</td>
<td>0.67 mN (0.150 mN, max)</td>
</tr>
<tr>
<td>Isp</td>
<td>1800 s (4,200 s, max)</td>
</tr>
<tr>
<td>Delta V (for 4kg spacecraft)</td>
<td>244 m/s</td>
</tr>
<tr>
<td>TRL</td>
<td>5</td>
</tr>
</tbody>
</table>
Busek 3cm RF Ion Thruster

Micro RF Ion Thruster
- Low Risk
  - Leverages NASA ST7 Technology flight development (cathode, valves)
  - Leverages NASA SBIR funding on a 400W RF ion thruster development
  - Leverages SBIR work on micro-valves and power management
- Innovative, patent-pending micro RF power generator
- Up to 2.5mN thrust and >3000sec Isp output
- Can deliver 6U Cubesat to Moon orbit

Remaining Development to Flight
- Additional performance point optimization
- Additional performance characterization
- Miniaturization of Electronics
- Package Design of the PPU and RF power generator
- Shock / Vibe / Thermal cycle
- Neutralizer position optimization (neutralizer is space qualified)

Key Performance Characteristics, Busek 3cm RF Ion Thruster

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>System Volume</td>
<td>&lt; 1.25 U</td>
</tr>
<tr>
<td>System Mass</td>
<td>~ 1.25 kg</td>
</tr>
<tr>
<td>System Power</td>
<td>&lt; 100 W</td>
</tr>
<tr>
<td>Thrust</td>
<td>1.9 mN (range 1 to 2.5 mN)</td>
</tr>
<tr>
<td>Isp</td>
<td>2,460 s (range 1,500 to 3,000 s)</td>
</tr>
<tr>
<td>Delta V (for 4kg spacecraft)</td>
<td>~4,000 m/s on 0.5 kg Xenon</td>
</tr>
<tr>
<td>TRL</td>
<td>5</td>
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</table>
Busek Micro Pulsed Plasma Thruster

Micro-Pulsed Plasma Thruster
✓ Integrated Primary & ACS Propulsion System
✓ Leverages MPACS, FalconSat-3 flight technology
✓ Leverages SBIR work on continued development and miniaturization
✓ Safe, Non-Toxic, Solid Propellant
✓ No moving parts
✓ Long storage shelf-life, wide operational temperature range

Remaining Development to Flight
✓ Direct thrust measurements to aid in stick geometry propellant optimization
✓ Final Electrical Design of PPU
✓ Final Package Design of the PPU
✓ Construct
✓ Shock / Vibe / Thermal cycle

Key Performance Characteristics, Busek Micro-Pulsed Plasma Thruster

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>System Volume</strong></td>
<td>&lt; 0.5 U</td>
</tr>
<tr>
<td><strong>System Mass</strong></td>
<td>&lt; 0.55 kg</td>
</tr>
<tr>
<td><strong>System Power</strong></td>
<td>2 W (at 2 Hz firing rate)</td>
</tr>
<tr>
<td><strong>Thrust</strong></td>
<td>0.5 mN, primary 0.13 mN, ACS</td>
</tr>
<tr>
<td><strong>ISP</strong></td>
<td>700 s</td>
</tr>
<tr>
<td><strong>Delta V</strong> (for 4kg spacecraft)</td>
<td>63 m/s, primary 65 m/s, ACS</td>
</tr>
<tr>
<td><strong>TRL</strong></td>
<td>5</td>
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</tbody>
</table>
Busek Micro Resistojet Thruster

Micro Resistojet Thruster
- Integrated Primary & ACS Propulsion System
- Resistojet is simplest electric propulsion
- Leverages SBIR work on micro-valves and power management
- Safe, Non-Toxic propellant
- Up to 10mN thrust output
- Life limit constrained by propellant storage
- Flight Prototype in final stages
- Can operate from <3 watts to >15 watts
- Isp and/or thrust increases with power
- Precise maneuvering possible
- Delivered integrated system prototype to USAF

Remaining Development to Flight
- Trade PPU design/components for cost versus rad hard
- Test complete system
- Shock / Vibe / Thermal cycle

Key Performance Characteristics, Busek MRJ Thruster (Primary Propulsion Unit)

<table>
<thead>
<tr>
<th>System Volume</th>
<th>1.0 U</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Mass</td>
<td>&lt; 1.25 kg</td>
</tr>
<tr>
<td>System Power</td>
<td>3-15 W</td>
</tr>
<tr>
<td>Thrust</td>
<td>2-10 mN, primary 0.5 mN, ACS</td>
</tr>
<tr>
<td>ISP</td>
<td>150 s, primary 80 s, ACS</td>
</tr>
<tr>
<td>Delta V</td>
<td>60 m/s, primary 6 m/s, ACS</td>
</tr>
<tr>
<td>TRL</td>
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</table>
Busek Green Monopropellant Thruster

**0.5N AF-315 Green Monopropellant Thruster**
- Integrated piezo microvalve, catalyst igniter and high temperature thruster body
- Busek’s microvalve fills the void of low-flow, low power, material compatible thruster valve
- Can be packaged into a 0.5U CubeSat system, including a fuel tank
- AF-315 is highly stable and non-toxic, yet performs better than SOA monoprop
- Leverages two concurrent SBIR Phase II work on microvalves and monopropellant thruster
- Precise firing and short impulse possible
- Stable operation demonstrated

**Remaining Development to Flight**
- System thermal management design
- Integrated system testing
- Maximum life testing and minimum impulse testing
- Environmental testing Shock / Vibe / Thermal cycle

**Key Performance Characteristics, Busek AF315 Green Monoprop Thruster**

<table>
<thead>
<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>System Volume</td>
<td>&lt; 1.5 U</td>
</tr>
<tr>
<td>System Mass</td>
<td>&lt; 1 kg</td>
</tr>
<tr>
<td>Power</td>
<td>&lt; 30 W</td>
</tr>
<tr>
<td>Thrust</td>
<td>500 mN</td>
</tr>
<tr>
<td>Isp</td>
<td>250 s nominalat 300 psi</td>
</tr>
<tr>
<td>Delta V (for 4kg spacecraft)</td>
<td>100 m/s</td>
</tr>
<tr>
<td>TRL</td>
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Summary

✓ Recognized industry leader in advanced space propulsion R&D for over 25 years

✓ Delivered flight qualified propulsion payloads to government customers.

✓ Leader in EP solutions for CubeSat and NanoSat Propulsion

✓ Eager to fulfill your CubeSat needs
Up to 6 Secondary Payloads attached to ESPA ring

Primary Payload

ESPA Ring

**Centaur upper stage**

**EELV Secondary Payload Adaptor Orbital Maneuvering System ESPA-OMS**

Adding Propulsion to ESPA makes it OMS

*Provided by Dr. Szatkowski, ULA*
ESPA OMS Concept, Delivers ~27 of 3U Cubesats to Mars and then serves as a communications relay back to earth.

- Propulsion Modulus: Cluster of 4 BHT-1500, gimbal, PPU's, and flow control.
- 4 tanks with 800kg of Xe.
- 4kW array at BOL.
- 27 P-Pods, each can house up to 5U CubeSat.

Potentially stimulating broad international participation, nations could fly their own Cubesats to Mars.