CubeSat Propulsion using Electrospray Thrusters

Tom Roy, Nathaniel Demmons, Vlad Hruby, Nathan Rosenblad, Peter Rostler and Douglas Spence

Busek Co., Natick, MA 01760

Paper SSC09-II-6
Technology Demonstration: ST7-DRS Mission

A demonstration mission for in-space verification of sensor and propulsion technologies required for LISA.

<table>
<thead>
<tr>
<th>Select ST7 Microthruster Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust Range</td>
</tr>
<tr>
<td>Thrust Resolution</td>
</tr>
<tr>
<td>Thrust Noise</td>
</tr>
<tr>
<td>(1mHz to 30mHz)</td>
</tr>
<tr>
<td>Throttle Time</td>
</tr>
</tbody>
</table>

20µN 
Av Thrust (1 mosquito)

0.1µN 
Resolution (1 antenna)
Background:
Electrospray Thrusters

\[ T = C_n I^{3/2} V^{1/2} \]

- The electric field between the capillary and opposing electrode (extraction grid) opposes surface tension forming a Taylor cone.
- At the apex of the cone the surface tension is overcome by the electrostatic forces and a thin jet is drawn from the cone.
- At some point downstream instabilities cause the jet to break up into a plume of monodisperse droplets.

Electrospray of conductive ionic liquid in vacuum.
ST7-DRS Functional Testing
ST7 Thrusters → CubeSats

- Two dimensional emitter, with self distributing emission points.
- No moving parts (e.g. valve) (mass, volume, power and cost savings)
- High thrust density (100x more current than ST7 capillary)
- Benefits from extensive ST7 characterization
- Multiple start / stop capability
Thruster Prototype

Extractor

2D Emitter

S/C Ground

Reservoir & Electrical / Thermal Isolation

<table>
<thead>
<tr>
<th>Developer: Busek</th>
<th>CubeSat Electrospray Thruster</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Size</td>
<td>&lt; 0.5U</td>
</tr>
<tr>
<td>System Wet Mass</td>
<td>0.5kg</td>
</tr>
<tr>
<td>(Thruster + PPU)</td>
<td></td>
</tr>
<tr>
<td>Total Propellant</td>
<td>.06kg (40mL)</td>
</tr>
<tr>
<td>Mass</td>
<td></td>
</tr>
<tr>
<td>Total Typical</td>
<td>2W</td>
</tr>
<tr>
<td>Power</td>
<td></td>
</tr>
<tr>
<td>Isp</td>
<td>800s</td>
</tr>
<tr>
<td>Thrust</td>
<td>0.1mN</td>
</tr>
<tr>
<td>Propellant</td>
<td>ionic liquid</td>
</tr>
<tr>
<td>Total Impulse</td>
<td>480 s</td>
</tr>
<tr>
<td>Delta-V (initial</td>
<td>495 m/s</td>
</tr>
<tr>
<td>mass 1kg)</td>
<td></td>
</tr>
<tr>
<td>Thrust-Power</td>
<td>0.05mN/W</td>
</tr>
<tr>
<td>Thrust Efficiency</td>
<td>~80%</td>
</tr>
<tr>
<td>TRL</td>
<td>5</td>
</tr>
</tbody>
</table>
Direct Thrust Validation
CubeSat Mission Expansion

1. FORMATION FLYING
   • Cost savings – deliver CubeSats to one location, allowing payloads to self-distribute
   • Mission modification (fill in coverage gaps in event of single Sat failure)

2. PLANE CHANGE
   • 800km circular orbit
   • 2.7° plane change in just under 1 yr
   • Assumes operation 15% of orbit, 100μN thrust / 800s specific impulse, 1U/1kg s/c

3. ORBIT MAINTENANCE
   • Can maintain a 1U / 1kg cubesat at 300km for 300 days
   • Assumes operation during 50% of the orbit, 10cm x 10cm exposed surface area for drag
   • For example, earth observation mission (300km instead of 800km improves resolution for the same imager)

4. DEORBIT
   • 800km circ → 200km elliptical deorbit
   • 1kg CubeSat w/ 100uN thruster (x1)
   • Requires 34% of std 40mL propellant reservoir

Background image from: http://www.universetoday.com
Closing Remarks

• Colloid Thruster technology has been flight-qualified, delivered, and scheduled for launch in 2010 on NASA ST7 mission.

• Planned 90,000 hr. LISA mission system engineering in-process

• Simplified variation has been developed for CubeSats:
  ➢ Mechanical simplicity: no moving parts
  ➢ Zero pressure propellant storage
  ➢ Small volume, mass, power
  ➢ Mission-specific tailored performance
  ➢ High delta-V unit improves CubeSat versatility and relevance

Come see the prototype of the CubeSat electrospray thruster at the Busek booth
Acknowledgements

This work was supported by

Air Force Research Laboratory Space Vehicles Directorate

Jet Propulsion Laboratory.