Cubesat Micropropulsion Characterization in Low Earth Orbit

1. Micropropulsion Technology R&D
2. The satellite POPSAT-HIP1
3. In Orbit Experiments
4. Conclusions

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TECHNOLOGY R&D
Collaboration with AIST, Tsukuba - Japan
MICRONOZZLES R&D

Specific Impulse Profile - 12C5 Nozzle

POPSAT Qualification
### Inertia

<table>
<thead>
<tr>
<th>Inertia</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>Kg</td>
<td>3.3</td>
</tr>
<tr>
<td>Px</td>
<td>kgm²</td>
<td>0.043</td>
</tr>
<tr>
<td>Py</td>
<td>kgm²</td>
<td>0.045</td>
</tr>
<tr>
<td>Pz</td>
<td>kgm²</td>
<td>0.009</td>
</tr>
</tbody>
</table>

### Torquers

<table>
<thead>
<tr>
<th>Torquers</th>
<th>Axis</th>
<th>Max.Mom¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>X</td>
<td>0.145 Am²</td>
</tr>
<tr>
<td>B</td>
<td>Y</td>
<td>0.145 Am²</td>
</tr>
<tr>
<td>C</td>
<td>Z</td>
<td>0.110 Am²</td>
</tr>
</tbody>
</table>

### Thrusters

<table>
<thead>
<tr>
<th>Thrusters</th>
<th>Axis</th>
<th>Arm CoM</th>
</tr>
</thead>
<tbody>
<tr>
<td>S4</td>
<td>+X</td>
<td>0.167m</td>
</tr>
<tr>
<td>12B5</td>
<td>(+X)</td>
<td>0.052m</td>
</tr>
<tr>
<td>7C5</td>
<td>+Y</td>
<td>0.180m</td>
</tr>
<tr>
<td>V4</td>
<td>+Z</td>
<td>0.061m</td>
</tr>
<tr>
<td>7E5</td>
<td>-X</td>
<td>0.167m</td>
</tr>
<tr>
<td>V5</td>
<td>(-X)</td>
<td>0.052m</td>
</tr>
<tr>
<td>12C5</td>
<td>-Y</td>
<td>0.180m</td>
</tr>
<tr>
<td>V1</td>
<td>-Z</td>
<td>0.061m</td>
</tr>
</tbody>
</table>

¹ at 25°C
Micropropulsion

[Diagram of micropropulsion system with labels: Tank, Pressure Sensor, PRG Valve, Isolation Valve, Nozzle Valves, Yaw and Pitch Thrusters (front of the satellite), Roll Thrusters (side of the satellite).]
Micronozzle Characterization (before launch)
POPSAT Launch

19 June 2014

POPSAT-HIP1

By DK3WN

Orbit experiments:
Isolation Valve & Gas Pressure Profile

- Top graph: Pressure (bar) vs. time (s)
  - X-axis: Time (s) from 0 to 10
  - Y-axis: Pressure (bar) from 0 to 8
  - Two lines: HI-P chamber (blue) and LO-P chamber (red)

- Bottom graph: Pressure (bar) vs. time (day)
  - X-axis: Time (day) from 0 to 300
  - Y-axis: Pressure (bar) from 0 to 8
  - Two lines: HI-P chamber (blue) and LO-P chamber (red)
  - Purple box labeled "micropropulsion idle"
Orbit experiments: Nominal performances
Experiment Operation

POPSAT contact (AOS)
Check Battery, etc...
Check Stabilization
Angular rate OK?

2min

Decide Axis Maneuver
Switch ON propulsion
Log Tank Pressure

1min

Switch OFF propulsion

3 to 4 min

Decide Thrust Level
Fire – Fire – Fire !!!
Log Angular Rate
Log Tank Pressure
Orbit experiments: Attitude Control

[14/12/2014 11:30:55 SGT] csp-term # fsm now
Current State: NOM

[14/12/2014 11:30:57 SGT] csp-term # fsm goto prm
[14/12/2014 11:31:03 SGT] csp-term # fsm now
Current State: PRM

[14/12/2014 11:31:22 SGT] csp-term # hk getadcs 1 1 0 1
2014-12-14 11:31:20 SGT
w = 0.07 -0.09 -0.64 [dps]

[14/12/2014 11:31:26 SGT] csp-term # fp commandrunspawn 26
[14/12/2014 11:31:29 SGT] csp-term # log get info 1 0 1
2014-12-14 03:31:28 : LOG_INFO VACO_GPR_REQ A:194 | B:46
[14/12/2014 11:31:31 SGT] csp-term # fp commandrunspawn 23
100 3 90 2 5 0 2 50

[14/12/2014 11:32:08 SGT] csp-term # hk getadcs 1 1 0 1
2014-12-14 11:32:05 SGT
w = 0.06 -0.42 -0.56 [dps]

[14/12/2014 11:32:11 SGT] csp-term # fp commandrunspawn 23
100 3 90 2 5 0 2 50
[14/12/2014 11:32:14 SGT] csp-term # fp commandrunspawn 27
[14/12/2014 11:32:25 SGT] csp-term # hk getadcs 1 1 0 1
2014-12-14 11:32:25 SGT
w = 0.06 -1.04 -0.55 [dps]

..........
Orbit experiments:
Angular velocity change

28 November 12:25 SGT - Firing P 1.78bar DC 90% axis +Y for 10sec x 3

9 January 11:14 SGT - Firing P 1.36bar DC 4% and 2% for 10sec each

23 December 12:01 SGT - Firing P 1.48bar DC 90% axis –X (8) for 10sec x 3

27 January 10:42 SGT - Firing P 1.3bar DC 90% axis +X for 10sec x 2
Orbit experiments:

**Bang-Bang**

1. 14 December 11:28 SGT - Firing P 1.62bar DC 90% axis -Y 10sec x 4 followed by axis +Y 10sec x 3

2. 18 December 10:50 - Firing P 1.56bar DC 90% axis +X (6) for 10sec x 3 followed by axis -X (5) for 10sec x 5

**Target Pointing**

1. 1 February 11:50 SGT - Firing P 1.2bar for 10sec each axis +Y DC: 2% 2% 4% 10% followed by axis -Y DC: 60% 10% 5% 2% 2%

2. 1 March 11:57 SGT - Firing P 1.15bar axis +Y DC 2% 4% 8% for 10sec each followed by axis -Y 10% 5% 2% for 10sec each
Orbit experiments:

**Bang-Bang**

14 December 11:28 SGT - Firing P 1.62bar DC 90% axis -Y 10sec x 4 followed by axis +Y 10sec x 3

Maneuver:

160 deg rotation
2 min 30 sec
### Orbit experiments:

**Conclusions:**

Cubesat Attitude Control

Micropropulsion TRL9!

<table>
<thead>
<tr>
<th>Description</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average specific impulse on EOL experiments</td>
<td>$I_s$</td>
<td>31.8 sec</td>
</tr>
<tr>
<td>Average specific impulse on mission</td>
<td>$I_s$</td>
<td>43.0 sec</td>
</tr>
<tr>
<td>Initial pressure</td>
<td>$P_0$</td>
<td>7.8 bar</td>
</tr>
<tr>
<td>Total mass</td>
<td>$m_0$</td>
<td>24 g</td>
</tr>
<tr>
<td>Total ΔV on 9 months mission</td>
<td>$\Delta v$</td>
<td>3.05 m/sec</td>
</tr>
<tr>
<td>Total ΔV for 1 month mission</td>
<td>$\Delta v$</td>
<td>5 m/sec</td>
</tr>
</tbody>
</table>
Thanks!
the Team (ready for the next one...)