Microspace Micropropulsion Roadmapping, Strategy and R&D Achievements

Introduction
Strategic Roadmapping
Tactical R&D program
Micronozzle Critical Development
Micropropulsion Systems
Application on Cubesat & Nanosat

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5.0kV X130 100μm WD 8.0mm
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Microspace Nanosatellite micropropulsion offer.

A hybrid technology, highly modular miniaturized, MEMS based system.
**Mission target:**
To bring to reality the concept of micropropulsion for nanosatellites

**Methods:**
To operate together with important players and the best partners and optimally tuned mix of mission driven technologies

**Constraints:**
To limit external constraints by keeping an independent identity to fulfill the mission efficiently and effectively
Roadmapping, dimensions problem breakdown:

- Strategic targets
- Application field
- Potential markets, actual clients
- Specifications and requirements

- System, subsystem, devices, parts breakdown
- Physical behaviors
- Manufacturing technologies
- Competencies and human resources

- R&D Financing
- Governments policies and politics
- Client-prime-subcontractors interaction
- Geography, logistics, borders
- Promotion and know how protection
- Time
From strategy to planning
Targets and methods are analyzed under the constraints to produce priorities among the methods and planning in the achievement of the targets. Tools such as Quality-Function-Deployment (QFD) are used.
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Strategy Roadmap
ESA – 2002: TOS-MPC/2168/ML

- Solid Propellant microthrusters
- Miniaturised solid prop. Cold gas generator
- Miniaturised Pyrotechnic Initiator
- Micro Electrical generator
- Microturbine
- Micropump
- Micro-reaction Chamber
- Propellant
- Microvalve
- Micronozzle
- CNT
- Metal hydrides
- Microspheres
- One-shot Microactuators
- Blow down Power generator
- Separation valve
- Turbo-Bipropellant Microthruster
- Cold Gas Microthruster
- Warm Gas Microthruster
- Chemical Microthruster
- H2 microstorage unit
- Micro-Nanosatellite Spinning DeOrbiting System
- Nanosatellite Attitude Control
- Nanosatellite Propulsion System
**Tactical plan** – 1st R&D iteration for Micronozzle building block: “exploration”

- System architecture selection
- Monodimensional thermodynamics
- Monodimensional losses estimation
- Basic CFD
- Technologies selection
- Micronozzle design
- Pendulum Microbalance design
- Micronozzle fabrication demonstration
- Microbalance construction
- Micronozzle function demonstration

First satellite application
Lessons learned

2001 - 2002
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System
Architecture and thruster technology selection:

Cold-Gas Micropropulsion

Specifications

- microthrust
  0.01 – 10 mN
- intensity control
  0-100%
- duration control
  0.1 – 1000 s
- very high number of pulses
  10-1000/orbit
- good Ax
  1 – 100 m/s
- Miniaturized
  0.2 l, 0.2kg

\[ n = \frac{t_{\text{mission}}}{t_{\text{cycle}}} = \frac{t_{\text{mission}}}{4 \sqrt{\frac{2Q_{\text{max}}}{\omega}}} = \frac{t_{\text{mission}}}{4 \sqrt{\frac{2Q_{\text{max}}}{T/I}}} \]
<table>
<thead>
<tr>
<th></th>
<th>Monolithic integration on silicon</th>
<th>Hybrid integration of different technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available</td>
<td>Not completely</td>
<td>Yes</td>
</tr>
<tr>
<td>Necessary</td>
<td>No</td>
<td>Almost in any case</td>
</tr>
<tr>
<td>Sufficient</td>
<td>Not completely</td>
<td>Yes</td>
</tr>
<tr>
<td>Economical</td>
<td>No (considering infrastructures and development cost)</td>
<td>Cheapest at the moment</td>
</tr>
<tr>
<td>Flexible (easily changeable)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Customizable</td>
<td>Very difficult</td>
<td>Yes</td>
</tr>
<tr>
<td>Reparable</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Progressively developable</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Transferable to other fields</td>
<td>difficult</td>
<td>easy</td>
</tr>
</tbody>
</table>
Our choice

- valve – gas – nozzle based
- modular system
- hybrid assembly
Tactical plan – 2nd R&D iteration for Micronozzle building block: “engineering”
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2nd R&D iteration (3 years ago)

Micronozzle fabrication process optimization

Experimental design correlations
Mass – Volumes and Power budgets for nanosatellites:

Micropropulsion subsystem

- 200 – 300 cc
- 200 g
- 2 W (up to 10W for short time or with deployable solar panels)

### CUBESAT BUDGETS

<table>
<thead>
<tr>
<th>subsystem</th>
<th>mass</th>
<th>volume</th>
</tr>
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<tbody>
<tr>
<td>structure</td>
<td>100</td>
<td>50</td>
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<tr>
<td>electronics</td>
<td>300</td>
<td>350</td>
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<tr>
<td>power</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>payload</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>propulsion</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

### PROPULSION BUDGETS

<table>
<thead>
<tr>
<th>element</th>
<th>mass</th>
<th>volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>nozzles</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>electronics</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>valves</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>tank</td>
<td>80</td>
<td>200</td>
</tr>
<tr>
<td>structures</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td>200</td>
<td>300</td>
</tr>
</tbody>
</table>
Micropropulsion system impact on Cubesat architecture:

30% of the volume
30% of the mass
Tactical plan – 3nd R&D iteration for Micronozzle building block: "production"

- Technology foundry selection
- Micronozzle redesign
- Micronozzle fabrication
- Micronozzle performance check
- Microbalance improvements
- Application on customer satellites
- Transfer on other application fields

- Monodimensional thermodynamics
- Monodimensional losses estimation
- Improved CFD
- Proprietary design correlations

2006 - 2007
1st R&D iteration:

(5 years ago)

Micronozzle fabrication demonstration
2nd R&D iteration
(3 years ago)

Micronozzle fabrication process optimization
2nd R&D iteration (3 years ago)

Micronozzle fabrication process optimization

1mN Cold-Gas Microthruster

1mN Cold-Gas Microthruster

10mN Cold-Gas Microthruster

1mN Cold-Gas Microthruster throat detail
3rd R&D iteration (1 year ago)

Micronozzles production
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Microthruster Family
Other system parts
<table>
<thead>
<tr>
<th>Microthruster family</th>
<th>modular elements growth</th>
<th>continuous learning process</th>
<th>Cubesat suitable</th>
<th>easy performance customization</th>
<th>affordable R&amp;D</th>
<th>affordable price</th>
</tr>
</thead>
</table>

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<table>
<thead>
<tr>
<th>engine</th>
<th>Cold-Gas</th>
<th>Warm-Gas</th>
<th>Vaporizing</th>
<th>Bipropellant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust (mN)</td>
<td>0.01 - 10</td>
<td>0.01 - 10</td>
<td>0.1 - 10</td>
<td>0.1 - 10</td>
</tr>
<tr>
<td>Specific imp. (s)</td>
<td>30 - 50</td>
<td>60 - 100</td>
<td>60 - 100</td>
<td>100 - 200</td>
</tr>
<tr>
<td>Δv (m/s)</td>
<td>1 m/s</td>
<td>2 m/s</td>
<td>200 m/s</td>
<td>300 m/s</td>
</tr>
<tr>
<td>mass</td>
<td>20g</td>
<td>35g</td>
<td>40g</td>
<td>60g</td>
</tr>
<tr>
<td>Volume (tank excl.)</td>
<td>5cc</td>
<td>9cc</td>
<td>10cc</td>
<td>15 cc</td>
</tr>
<tr>
<td>Options</td>
<td>Up to 8 nozzles; Press. Feedback</td>
<td>1, 2, 3 or 4 nozzles; Press. Feedback</td>
<td>1 nozzle; Press. Feed-back</td>
<td>1 nozzle; Press. Feed-back; Mix control; Heat regeneration</td>
</tr>
<tr>
<td>status</td>
<td>Mission ready</td>
<td>Mission ready</td>
<td>Qualification</td>
<td>Prototyping: testing</td>
</tr>
</tbody>
</table>
Complete Micropropulsion systems:
✓ Cubesat, nanosatellites, microsatellites
✓ Modular
✓ Miniaturized
✓ Customized
✓ Qualified
✓ Affordable
✓ Ready

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Also special thanks to: