Low Cost Helicon Propulsion System for CubeSat future mission scenarios

T4i - University of Padova
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Technology for Propulsion and Innovation
a University of Padua Spin-off
Padova, Italy
Electric Propulsion Systems for small satellites

The Helicon Plasma Thruster option
Outline

• Who we are

• Helicon Technology

• Main benefit of Helicon Technology

• Helicon Plasma Thruster development @ University of Padova

• MHT for small platforms @T4i

• Conclusions
UNIPD-CISAS staff member are 39 scientist, belonging to several departments of the University and to the Astronomical Observatory of Padova, some of them are among pioneers of space research in Italy.

UNIPD-CISAS research group is composed also by about 50 people among technical personnel, post doc, PhD students.

UNIPD-CISAS research is conducted in laboratories made available by the funding department but also its own laboratory equipped with sophisticated instrumentations.

UNIPD-CISAS Participates to several major NASA-ESA-ASI mission as: SOHO, Cassini-Huygens, Rosetta, Mars Express, Venus Express, ExoMars, GOCE, BepiColombo etc.

http://cisas.unipd.it

The major fields of expertise are:

- Astronomy and Astrophysics
- Geo-dynamics
- Orbital Dynamics
- Space Geodesy
- Space Medicine
- Space Navigation
- Space Optics
- Space Structures
- Systems Engineering
- Payload Instruments
- Planetary Sciences
- Space Robotics
- Space propulsion
Technology for Propulsion and Innovation

T4i is a Spin-Off of the University of Padua, born in March 2014.

The Spin-Off has been founded by the Propulsion Group of the University of Padua and an entrepreneur. Today it counts 15 people with strong expertise in managing demanding and advanced systems development projects in the aerospace sector and technology transfer activities.

T4i commitment is to inject innovative product and services into the market as a result of more than 10 year of research within the space propulsion group of University of Padua.

T4i competence ranges from chemical propulsion to electrical propulsion aerospace engineering design, development, simulation and tests.
The team

- 1 Associate professor
- 9 senior engineers
- 1 young engineer
- 4 PhD students

iCubeSat 2017 Cambridge (UK)
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The electrodeless RF plasma thruster basically consists of a RF plasma source, where the plasma is generated and heated, and thanks to a magnetic nozzle / potential drop is accelerated into vacuum.

- The plasma marginally interacts with the structure therefore the erosion is reduced.
- Internal electrodes are absent.
- The exhaust beam is neutral thus an external neutralizer is not needed.
- It can potentially operate with different propellants.
- One feeding line
- One Power Line
Helicon thruster

- RF Power
- Matching system
- Antenna
- Magnetic field

Propellant storage
Plasma chamber
Acceleration Stage (magnetic nozzle)
Plasma detachment from the magnetic nozzle

Stage #1 Plasma-Wave interaction
Stage #2 Plasma internal dynamics
Stage #3 Plasma acceleration in the magnetic nozzle
Stage #4 Plasma detachment

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## Main benefits of HPT

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<tr>
<th>Key features</th>
<th>Advantages</th>
<th>Benefits</th>
</tr>
</thead>
</table>
| No electrodes (no cathodes and anodes exposes to plasma)  | No electrodes subjected to deterioration  
Increased overall system simplicity                                                                | Suitable for high Total DeltaV missions, enabling different and **new mission** scenarios  
and interplanetary flights.  
**Long lifetime.** |
| No neutralizers and grids                                 | Increased overall system simplicity                                                              | **Low** development and recurrent production **costs**                                        |
| Intense knowledge of plasma production and acceleration physics | Capability to translate customers’ specific needs in technical requirements and to  
scale the system                                                                                     | Low development costs for **customization** to match customers’ particular needs               |
| Versatile technology                                      | Ability to work with many different gases also reactive or oxidants.  
System flexibility.  
Throttability 1:10                                                  | Flexibility of the system to **adapt** to different **mission** scenarios  
Flexibility of the system to match customers’ particular needs                                   |
| Propulsion box                                            | Compact propulsion unit  
With standard interface                                                                                     | Easy **integration**                                                                          |
Enabled operations

- High Delta V missions for multiple U satellites / mini satellites
  - Orbit maintenance / continuous drag compensation
  - Orbit configuration / re-configuration
  - End of life disposal
  - Exploration and complex scientific missions

- Utilization of chemical propellant vapours or pressurization gas for HPT usage

- International Space Station wastes enabled missions
  - Satellite Deorbiting
  - Satellite Servicing and Refuelling
  - ISS Orbit rising
  - Deep Space and Moon missions from ISS

- Human missions
  - Cis-lunar, Moon and NEOs exploration roadmap
  - Human mission to Mars
Enabled operations

• Atmospheric Breathing enabled mission
  – Planets and moons explorations
    • Permanent exploration missions on planets and moons with atmosphere: Venus, Mars, Titan, Uranus, Neptune, Saturn, Jupiter
    • Permanent orbiter/drone on Mars
  – Refuelling and sample return from rocky planets and moons with atmosphere
    • Refuelling and sample return from rocky planets and moons with atmosphere: Mars, Venus, Titan
  – Earth missions
    • Observation missions with drag compensation on Earth
    • Earth active debris removal with refuelling during deorbiting phase

• Celestial body mining byproducts enabled missions
  • Asteroid soil volatiles exploiting
  • Lunar soil volatiles exploiting
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Jan 2009  Start of the HPH.com Program
Jun 2009  First helicon source operational
Jan 2010  1-D plasma simulation code operational, first thruster lab model operational

Jun 2010  First high efficiency source operational
Jan 2011  First thruster EM
Jan 2012  Code completed, advanced thruster design
Jun 2012  EM final development and test
The first HPT EM was realized in cooperation with KhAI under the FP7 program HPH.com which ended in June 2012.

Thruster main characteristics:

- **Power**: 50 W
- **Thrust**: 1.5 mN
- **Isp**: 1350 s
- **Efficiency**: 20%
- **Working gas**: multiple
- **Mass**: 1.2 kg
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The thruster EM was consequently optimized to get a new EM.

The technology was updated to get:
• Lower mass and size targeting nano to micro satellite markets
• Lower complexity and costs

The new technology is flexible and versatile to achieve different thrust level requirements with very limited modifications.

The complete system fits in a 100x100x100 mm envelope, with standard data and power interfaces with the satellite.

In function of the required Total Impulse, the propellant tank has different sizes.
MHT for mini Platforms

PCU: Power Control Unit
PPU: Power Processing Unit
FCU: Flow Control Unit
PT: Propellant Tank

Mechanical / Electrical Interface with Satellite

Power
Data
Diagnostics
Gas

Thruster
PCU
PPU

Matching System

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Key subsystems: PPU

- Prototype tested at ≈ 200 W up to 2 MHz
- Results:
  - Efficiency up to 80-87% with first prototype
  - Limited waveform distortion

**Efficiency ≈ 80%**

**Power from supply ≈ 170W**
MHT actual performances

![Graph showing actual performances of MHT with different thrust levels and power inputs. The graph includes data points for 0.1 mg/s, 0.056 mg/s, 0.125 mg/s, and 0.15 mg/s, with corresponding thrust and power values.]
MHT actual performances

![Graph showing actual performances of MHT with different Isp values for different P to thrust rates.](image)

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MHT on Multi U

Payload section (physics experiments, e.g. silicon detector) – 2U

Xenon Feed System (tanks, fluidics) – 1U
Tank size depends on Mission profile

Service section – 2U

6U scientific mission conceptual layout

Helicon thruster and PPU – 1U

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8 kg dry mass satellite 60 W power around the moon

**Lunar Transfer Orbit**

<table>
<thead>
<tr>
<th>Dv [m/s]</th>
<th>mp [kg]</th>
<th>tb [days]</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3900</td>
<td>5.97</td>
<td>691.45</td>
<td>Smart 1 orbit injection</td>
</tr>
<tr>
<td>4500</td>
<td>7.23</td>
<td>836.37</td>
<td>intermediate orbit</td>
</tr>
<tr>
<td>6950</td>
<td>13.62</td>
<td>1575.88</td>
<td>from 600 km</td>
</tr>
</tbody>
</table>

**Moon maneuvers starting from 700 km**

<table>
<thead>
<tr>
<th>Dv [m/s]</th>
<th>mp [kg]</th>
<th>tb [days]</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.24</td>
<td>0.03</td>
<td>3.75</td>
<td>From 700 km to 800 km</td>
</tr>
<tr>
<td>194.3</td>
<td>0.23</td>
<td>26.09</td>
<td>5° inclination changing</td>
</tr>
<tr>
<td>94.72</td>
<td>0.11</td>
<td>12.63</td>
<td>Eccentricity from 0 to 0.1</td>
</tr>
</tbody>
</table>

**Moon maneuvers starting from 100 km**

<table>
<thead>
<tr>
<th>Dv [m/s]</th>
<th>mp [kg]</th>
<th>tb [days]</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>42.73</td>
<td>0.05</td>
<td>5.68</td>
<td>From 100 km to 200 km</td>
</tr>
<tr>
<td>223.78</td>
<td>0.26</td>
<td>30.11</td>
<td>5° inclination changing</td>
</tr>
<tr>
<td>109.09</td>
<td>0.13</td>
<td>14.56</td>
<td>Eccentricity from 0 to 0.1</td>
</tr>
</tbody>
</table>
MHT Development status

Engineering Model Development and testing Q3 2017
Qualification Model development and testing Q1 2018
Flight currently scheduled by end 2018
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Mini Helicon technology represent a viable option for small satellite
Performance and cost looks a good compromise for small platform
A development program to make it flying is currently ongoing at T4i.

.... To be continued......
If you are interested in knowing more about T4i, our capabilities and offers, you can contact:

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