System Analysis and Test-Bed for an Atmosphere-Breathing Electric Propulsion System using an Inductive Plasma Thruster

Presentation - September 2017

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System Analysis and Test-Bed for an Atmosphere-Breathing Electric Propulsion System using an Inductive Plasma Thruster


28th September 2017

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under agreement No 737183

Institute of Space Systems
University of Stuttgart
Motivation

Low altitude orbits have advantages:

• Higher resolution imaging and measurements;
• Less complicated instrumentation → lower mass and costs;
• S/C’s stabilization by aerodynamic forces.

...but atmosphere works against us:

• Momentum exchange between atmosphere and S/C;
• Decrease of orbital velocity, shorter mission
  but also enabling “self” End-of-Life disposal!

⇒ Drag has to be counteracted.
What kind of propulsion system is needed?

- Efficient propulsion system for small S/C to compensate the drag;
- Electric propulsion → low thrust, high $I_{sp}$;
- Scalable to small sizes, variable thrust, efficiency;
- Looking at $I_{sp}$ and scalability to small S/C we choose electric propulsion.

Great amount of drag to be compensated for most mission time, 
→ requires a great amount of propellant to be carried on-board
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Low drag, atomic oxygen resistant materials

Aerodynamic attitude and orbit control

Very Low Earth Orbit Satellite Concepts

Atmosphere-breathing electric propulsion

Combined system and business models

IRS Main Task

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Atmosphere-Breathing Electric Propulsion (ABEP)

- Use of residual atmosphere as propellant for an electric thruster;
- Intake collects the atmosphere molecules and feeds the thruster;
- Thruster process and expel them through a nozzle to generate thrust.

Universe of Stuttgart

68th International Astronautical Congress, Adelaide, Australia
Very Low Earth Orbit – VLEO

- ABEP S/C will encounter mostly atomic O and N\(_2\)
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<table>
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<th></th>
<th>ESA RAM-EP</th>
<th>ABIE JAXA</th>
<th>MABHET</th>
<th>RPT Shab.</th>
<th>RAM-HET SITAEL</th>
<th>IRS - DISCOVERER</th>
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<tr>
<td>$P$, kW</td>
<td>1</td>
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<td>$\eta_c$</td>
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<td>&lt;0.45</td>
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<td>0.9</td>
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<td>$h$, km</td>
<td>180-250</td>
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<td>&gt;150 (Mars)</td>
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<td>$A_{front}$, m²</td>
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<td>0.12</td>
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</table>
Facility Refurbishment

- Tank of 12 m³ previously used for RIT testing;
- Main vacuum facility < 1 Pa with no mass flow;
- Secondary system: Oil diffusion pumps (50 000 l/min) \( \sim 10^{-4} \) Pa with no mass flow.
Inductive Plasma Thruster (IPT) – Starting from IPG6-S

- RF-fed electrodeless device;
- Discharge channel diameter 40 mm;
- Water cooled;
- Power input max 15 kW, f~4 MHz, I up to 4.5 A;
- Propellant: O₂, N₂, CO₂.

- Any gaseous propellant can be used;
- No neutralizer needed;
- No components in direct contact with the plasma → erosion free
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de Laval-Modular Nozzle

- External nozzle structure attached to IPG6-S water cooled bottom flange.
- Water inlet/outlet
- Water cooling channel
- Convergent section inserted
- Closure added, convergent-only configuration
- Divergent section added, de Laval configuration
Inductive Plasma Thruster - IPT

- Based on IPG6-S experience;
- Passively cooled;
- Dimensions optimized for ABEP related mass flow;
- Optimized antenna for best power coupling;
- Acceleration stage;
- Optimized for input power 0.5 to 5.5 kW.
Conclusion

• Solid and verified literature review available for ABEP development;
• IPG6-S has now an upgraded facility that allows more reliable test results;
• A modular de Laval nozzle has been designed and built;

Outlook

• The new test facility serves as test-bed for the development of the IPT;
• Calorimeter measures the plasma plume energy, mini Pitot probe will be soon integrated;
• Understanding and modification on the power supply will allow better operation;
• Inclusion of external B-field and magnetic nozzle to improve IPG6-S.
Thank you for your time!

Questions? Suggestions?

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