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

Francesco Romano
Universität Stuttgart

Tilman Binder
Universität Stuttgart

INTERNATIONAL ASTRONAUTICAL CONGRESS 2017
ADELAIDE, AUSTRALIA • 25-29 SEPTEMBER 2017
68TH IAC ADELAIDE 2017
Unlocking imagination, fostering innovation and strengthening security.

IAC-17-C4,6,5,x41810

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

F. Romano, T. Binder, G. Herdrich, P. C.E. Roberts, S. Rodriguez- Donairee, D. Garcia-Almiñanae, N. H. Crisp, S. Edmondson, S. J. Haigh, R. E. Lyons, V. T.A. Oiko, K. L. Smith, J. Becedas, G. González, I. Vázquez, Á. Braña, K. Antonini, K. Bay, L. Ghizoni, V. Jungnell, J. Morsbøl, A. Boxberger, S. Fasoulas, D. Kataria, M. Davidson, R. Outlaw, B. Belkouchi, A. Conte, J. Santiago Perez, R. Villain, B. Heißerer, A. Schwalber

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

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

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.

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

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

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

DISCOVERER

5.7 M€
Horizon 2020 project

9
partners

4¼
years duration

6
countries

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

Low drag, atomic oxygen resistant materials

Aerodynamic attitude and orbit control

Very Low Earth Orbit Satellite Concepts

IRS Main Task

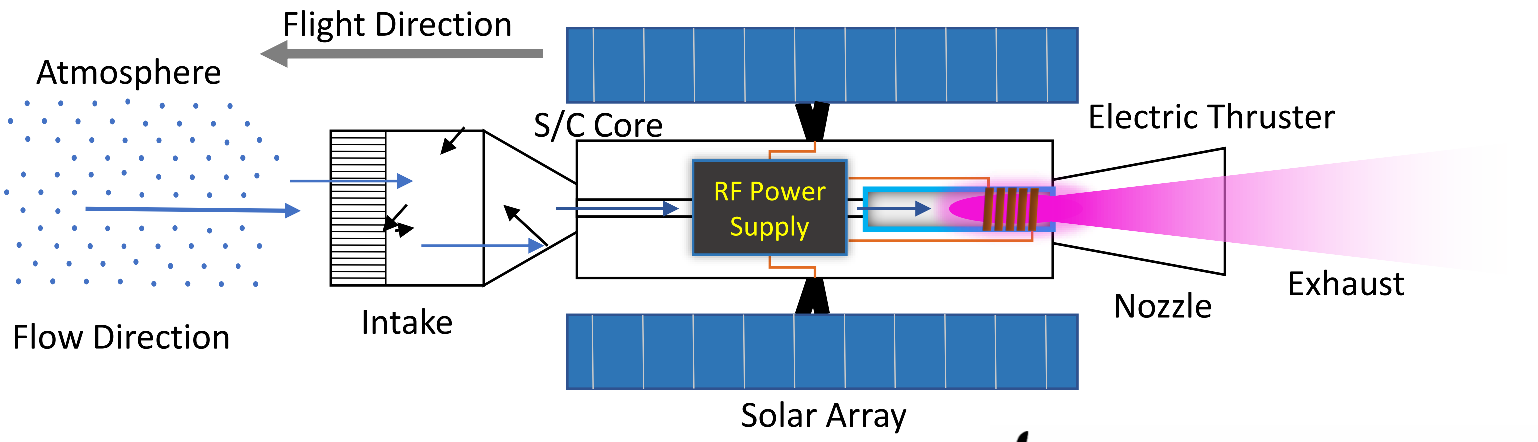
Atmosphere-breathing electric propulsion

Combined system and business models

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

Atmosphere-Breathing Electric Propulsion (ABEP)

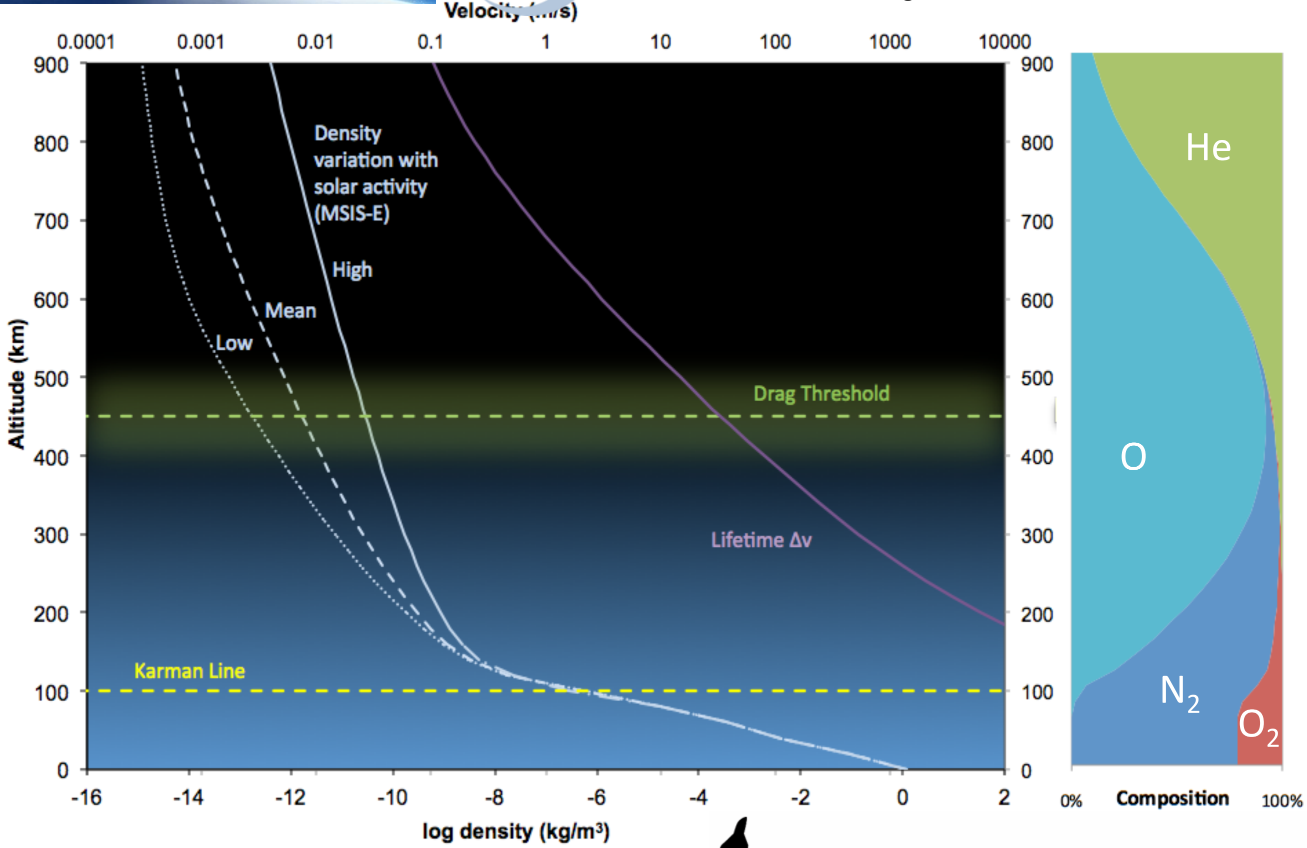
- Use of residual atmosphere as propellant for an electric thruster;
- Intake collects the atmosphere molecules and feeds the thruster;
- Thruster process and expel them through a nozzle to generate thrust.



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

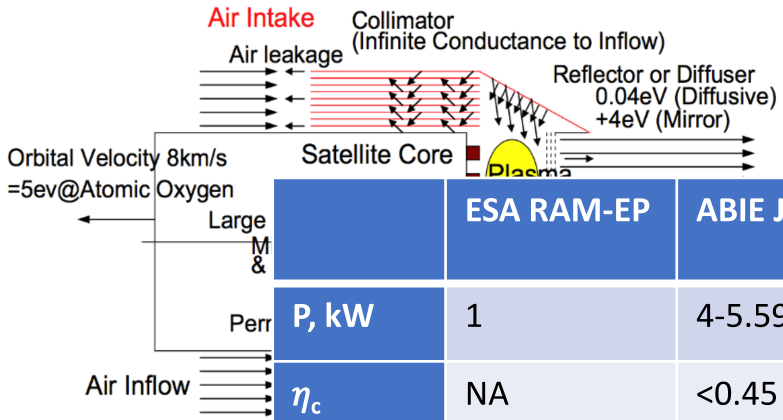
Very Low Earth Orbit – VLEO

- ABEP S/C will encounter mostly atomic O and N_2

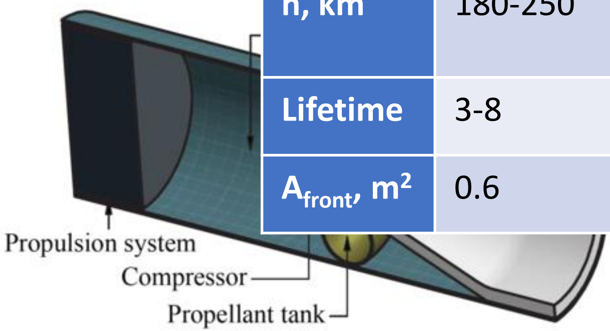


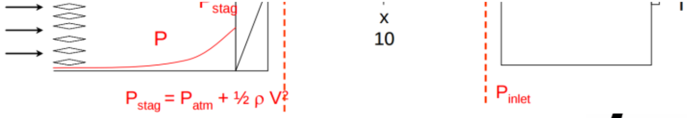
This project has received funding from the European Union's Horizon 2020 research and innovation programme under agreement No 737183

Literature Review



	ESA RAM-EP	ABIE JAXA	MABHET	RPT Shab.	RAM-HET SITAEL	IRS - DISCOVERER
P, kW	1	4-5.59	1-1.2	1-1.5	NA	0.5-5.5
η_c	NA	<0.45	0.35	0.9	NA	Optimizable
h, km	180-250	150-200	>150 (Mars)	200	200	120-250
Lifetime	3-8	>2	3	2-4	NA	Optimizable
A_{front}, m^2	0.6	0.48	0.15	0.13	0.12	1





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

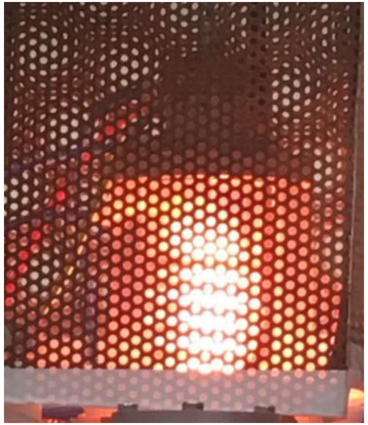
Facility Refurbishment

- Tank of 12 m^3 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.

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

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: O_2, N_2, CO_2.

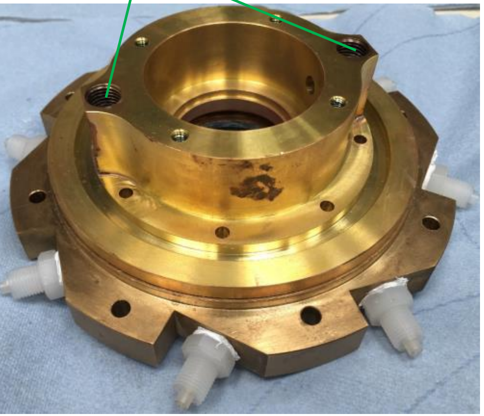


- Any gaseous propellant can be used;
- No neutralizer needed;
- No components in direct contact with the plasma → erosion free

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

de Laval-Modular Nozzle

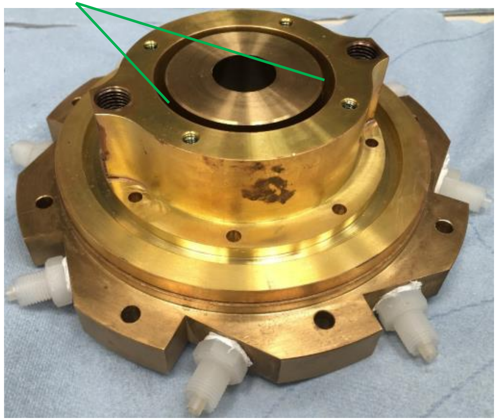
Water inlet/outlet

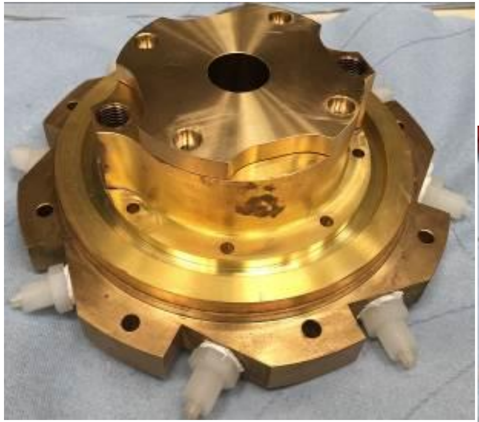


External nozzle structure attached to IPG6-S water cooled bottom flange.

Convergent section inserted

Water cooling channel





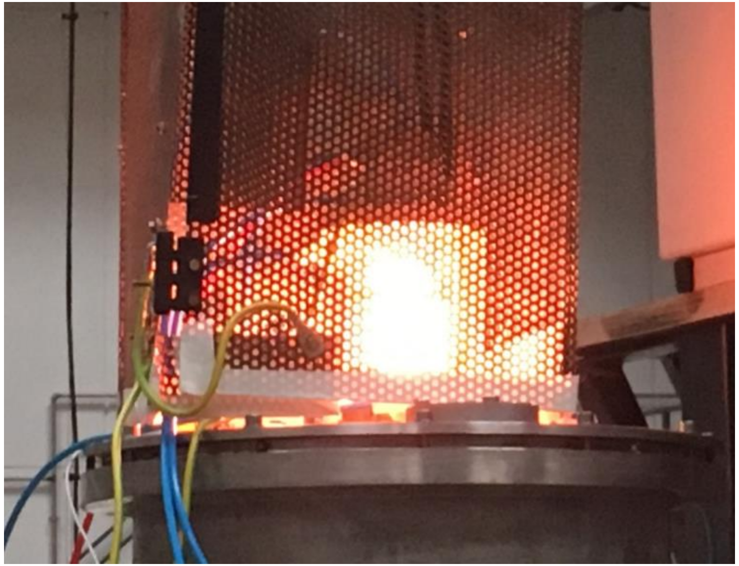
Closure added, convergent-only configuration

Divergent section added, de Laval configuration

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

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.



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

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 an 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.

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

Thank you for your time!

Questions? Suggestions?

Francesco Romano
romano@irs.uni-stuttgart.de
Pfaffenwaldring 29, 70569 Stuttgart, Germany