ESA Propulsion Laboratory

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Abstract: **Electric and chemical propulsion systems are very important for spacecraft applications. Performance and reliability of propulsion systems are two main areas that have to be demonstrated to any space project. Europe is developing several types of electric and chemical thrusters for application to many satellites. Design, manufacturing and testing of such thrusters is a complex activity that requires a great effort. Full characterisation, qualification, acceptance and plume interaction tests are mandatory in the full assessment of these technologies. The ESA Propulsion Laboratory (EPL) is an operational facility in the spacecraft propulsion testing field located at the European Space Research and Technology Centre of the European Space Agency, ESTEC located in The Netherlands. It provides test services to the ESA Propulsion and Aerothermodynamics Division, which is responsible at European Space Agency for R&D activities and support to projects in the areas of chemical propulsion, electric and advanced propulsion and aerothermodynamics. EPL obtained dual ISO 17025 accreditation and ISO 9001 certification in 2004. It performs accredited measurements for mass flow, thrust and electrical power for electric and cold gas thrusters and components. EPL offers support to ESA projects and develops technology required for ESA in the field of propulsion. In the last years, the activities of the laboratory, under project request, have been focused on testing electric propulsion systems below 2 kW. They have been expanded to low thrust measurements (microNewton) and chemical propulsion (cold gas and other non-toxic propellants).**

I. Introduction

SPACECRAFT propulsion systems are very important for space applications. Electric propulsion systems are baseline in several ESA (European Space Agency) missions which have been or will be launched in the near future: GOCE, Alphabus, SmallGEO, BepiColombo. Furthermore future missions like EUCLIDE, ELECTRA, AGILE, NEOSAT, etc. will require also electric propulsion systems to achieve stringent propulsion requirements as well as perform the orbit transfer. Chemical propulsion systems with microNewton range cold gas thrusters are also baselined in many ESA missions (GAIA, Lisa PathFinder, Microscope, etc.). The development of all these electric and chemical thrusters requires a great effort in the testing area[1]. Full characterization, qualification, acceptance and plume interaction tests are mandatory in the full assessment of these technologies.

The EPL is an operational facility at ESTEC in the spacecraft propulsion testing field[2]. The EPL provides test services to the ESA Propulsion and Aerothermodynamics Division, which is responsible at European Space Agency for research and development activities and support to projects in the areas of chemical propulsion, electric and advanced propulsion and aerothermodynamics. The main effort of EPL is directed towards the performance, endurance and assessment testing of propulsion systems for ESA missions. Moreover, the EPL increases its

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collaboration with international industry and Academy in the field of space propulsion research, development and testing.

This paper will present the activities, the structure and the capabilities of the EPL at ESA.

Figure 1. ESA Propulsion Laboratory at the European Space Agency in the Netherlands.

II. ESA Propulsion Laboratory Activities

The main purpose of the EPL is to supply services to ESA projects which require independent and fast assessment of propulsion technologies and related topics, including performance and possible failures. Projects among which GAIA, CryoSat, Lisa PathFinder, Microscope and SmallGEO have been or are currently using EPL capabilities. A test performed in the frame of the Lisa PathFinder project, involving the manufacturers of the micro propulsion RIT-µX thruster, shown in Figure 2, and its fluidic system, Astrium GmBH, the Power processing unit and the neutralizer, Selex Galileo ES, was recently carried out in an EPL vacuum facility to verify the neutralization concept[3,4,5].

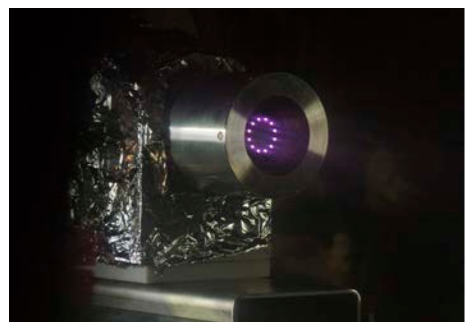


Figure 2. Mini-Ion Engine RIT-µX firing in the GIGANT facility of the EPL during neutralization test.

The laboratory also enables fast access to qualification and lifetime tests which are long and expensive in nature. For instance for the Artemis mission the EPL hosted the lifetime test of the Radio Frequency Ion Engine RIT-10 which accumulated about 22,000 hours[6]. Another example is the involvement of the laboratory during the development and the acceptance of the propulsion system for the SMART-1 spacecraft.

The EPL provides support to ESA Research and Development programs as well. It performs technologies assessment and explorative internal R&D work on new ones proposed by Industries and/or Laboratories. In the last few years, R&D activities on FEEP (Field Emission Electric Propulsion) technologies performed at the EPL helped all European companies and laboratories involved in this field. They allowed identifying the critical areas[7] of this technology and the way to proceed to solve the technology issues in an independent manner. Several tests devoted to the development of new engines such as mini-ion thrusters and mini-Hall Effect thrusters[8,9] that will be the baseline for future space missions have been and will continue to be hosted by the laboratory. High temperature resistojets designed and manufactured by Alta S.p.A have recently been tested in the EPL to measure their thrust[10].

Furthermore the EPL has established international scientific and technical cooperation. Back to 2010 in the frame of the Lisa PathFinder project with JPL a colloid thruster contamination test was performed in the EPL[11] allowing to remove the hypothesis of contamination of the colloid thruster by cesium. The EPL is today a reference for all the propulsion companies in Europe mainly in the field of electric propulsion testing and provide them with support in case it is required. Moreover, EPL is involved in the preparation of the network of electric propulsion facilities put it place in the last years. In collaboration with industry bodies, the objective is to standardize the way electric propulsion technologies are tested[1]. This will allow any customer to change testing facilities in case of logistics or technical problems, minimizing schedule and cost impact on the activities. The EPL helps in procedures definition and contributes actively to propose alternative solutions to the problems found in this field[12].

III. ESA Propulsion Laboratory Organization

The EPL is managed by the EPL manager with the support of the EPL infrastructure and Quality manager. The EPL responsible is the person in charge of the normal operation of the laboratory. The operation, maintenance and procurements are under the monitoring of the Head of the Propulsion and Aerothermodynamics division. The justification for investments (mainly for facilities, diagnostic packages and data acquisition systems) is performed by the EPL management together with the customers of the laboratory who are frequently consulted via a steering board.

For every test performed, a test team is formed. A senor test manager is in charge of the test and the team composed by senior and junior engineers. This organization helps not only to perform the test but also to train junior engineers who can therefore learn directly in the field under the supervision of the senior members of the team.

The ESA Mechanical department to which the EPL belongs has passed an accreditation and certification process carried out by the Dutch Accreditation Council (RvA). Dual ISO 17025 accreditation and ISO 9001 certification processes were obtained by the EPL in 2004 and since then are validated every year in annual audits. Therefore the procedures and reporting outputs are exposed to the demanding quality requirements of the accreditation body.

IV. ESA Propulsion Laboratory Facilities and Capabilities

The testing of propulsion systems requires facilities capable to simulate space conditions and which are designed for this scope. In some cases such as electric propulsion components (thrusters and neutralizers) the vacuum conditions must be better than 10^{-9} mbar. The European Space Agency has invested in the ESA Propulsion Laboratory to allow the Agency to assess the special characteristics of the electric and clod gas propulsion thrusters and components in the last decades. Lately, the laboratory has expanded its fields of application to other chemical propulsion activities such as testing of propulsion components (valves, injector, etc).

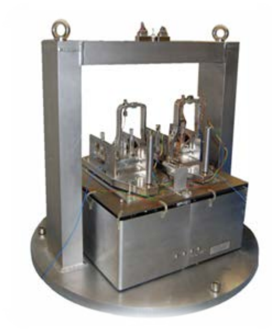
Figure 3. Langmuir and emissive probes with ICARE PPI thruster at EPL

The domain of competence of the EPL includes ISO 17025 accredited procedures for the direct and indirect measurements of thrust, mass flow and electrical power related to propulsion systems operation in specific ranges.

Features of testing facilities at EPL:

- Certification ISO 9001 (Quality Management)
- Accreditation ISO 17025 (General Requirements for the competence of testing and calibration laboratories)
- Cleanroom ISO Class 8 capability (eq. to class 100,000)
- Seismic block for noise isolation
- 7 vacuum facilities dedicated to space propulsion testing
  - Vacuum chamber reproducing space environment with pressure down to 10^{-9} mbar
  - Beam target and diffuser reducing on-ground testing disturbances
  - High speed high resolution data acquisition systems
- 1 flow bench (to be upgraded into water-hammer bench)
- Calibrated commercial measurement instruments
  - Various electronic equipment for measurements from 1 µV/1 nA to 35,000 V / 20 A
  - Mass spectrometers for residual gas analysis
  - Infrared Thermocamera
  - Pyrometer
- Customized measurement instruments with chain of calibration
  - 5 thrust balances for thrust measurement from microNewton to Newton ranges
  - 3 beam diagnostics systems for beam divergence and energy distribution measurements

Specific diagnostic systems available at the EPL include two Mettler-Toledo high precision (0.1 mg resolution) electronic load cells customized for micro and milliNewton thrust measurement of cold gas thrusters, two specifically designed thrust balances for milliNewton range electric propulsion thrusters. The design and manufacturing of very specific diagnostics is usually realized in collaboration with external entities. For instance, among others, two balances and several diagnostics (Faraday probes, Retarding Potential analyzers, etc.) were developed by ALTA S.p.A, ICARE designed and developed a retarding potential analyzer and its electronic system able to measure energies of primary and charge-exchange ions, the University of Stuttgart is developing a Langmuir Probe. Nevertheless the EPL has independent capabilities to carry out this kind of activities: lately Langmuir probe and emissive probes are being successfully used in the laboratory to determine the plasma parameters in a Hall Effect Thruster plume (Figure 3). A microNewton thrust balance[13] depicted in Figure 4 was developed in the past few years, in collaboration with the National Physics Laboratory (UK) to measure thrust in the microNewton range and noise. This balance is in the process to be validated to perform ISO 17025 accredited measurement for thrust only.



Range	0 – 500 µN
Resolution	0.5 µN
Bandwidth	4 Hz
Measurement Noise	< 1 µN/√Hz in range 10^{-3} – 100 Hz
Total uncertainty (steady-state)	1 µN (2σ)

Figure 4. EPL MicroNewton Thrust balance developed in collaboration with the National Physics Laboratory (UK) and its achieved performance.

The EPL is capable of designing, preparing and executing performance characterization and endurance tests of low and medium power electric propulsion thrusters and components in its automated vacuum facilities. Performance of components for chemical propulsion may also be measured.

The last few months a water flow rig bench (Figure 5) was commissioned in the EPL. Tests with calibrated orifices (flow restrictors) were successfully performed allowing demonstrating the limitations of the bench. A pressure panel was also assembled for the management of different inert gases used in chemical propulsion. An upgrade of the bench toward water-hammer experiments to measure pressure peaks due to fast opening/closing of valves is scheduled for 2013- 2014.

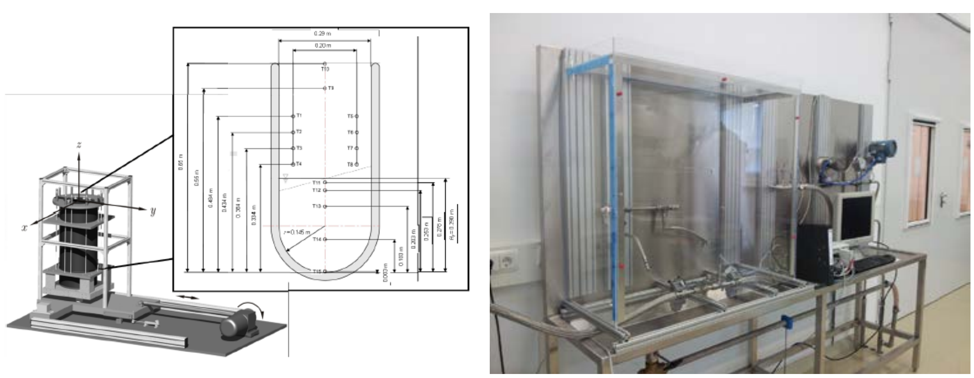


Figure 5. Sloshing bench (design) and EPL flow rig bench

New exploratory investigations such as spacecraft-thruster interaction tests are being performed at the EPL[13,14]. Ground-based vacuum facilities possess a low-density background neutral gas due to physical pumping limitations and to the leak rate of the vessel. The facility background gas present in the vacuum chamber can have undesirable effects on the measurement of electric propulsion thruster performance and plume characteristics. High-Energy exhaust particles interact with the neutral background particles through charge-exchange collisions. In the plume the effect of those collisions products are more evident in the vicinity of the thruster, where they lead to an increase in the measured current density. Several investigations are underway to model thruster performance and the interactions between ion thruster plumes and spacecraft. For simulations of laboratory experiments, ones of the most important inputs required by these codes is the backpressure in the vacuum chamber and the energy the incident ions[15] may have before impacting any spacecraft surface.

In the area of aerothermodynamics, a sloshing bench (Figure 5) is being designed in collaboration with NUMA (Ireland). It will initially be used to perform experiments for code validation using standard liquids such as water and later on liquid nitrogen. The facility will also be used to test measurements techniques. The tests will be conducted with an excitation frequency up to 3 kHz and amplitude up to 10 cm.

V. Conclusion

The ESA Propulsion Laboratory supports ESA projects and basic research and development of new propulsion systems at ESA. The EPL provides an independent performance assessment of propulsion technologies in the area of electric propulsion and cold gas thrusters. The domain of competence of the EPL includes ISO17025 accredited direct or indirect measurements of thrust, mass flow, and electrical parameters related to propulsion system operation. The EPL is often consulted for expert advice in all aspects related to spacecraft propulsion testing.

The EPL testing capability is currently focused on low/medium-power electric propulsion technologies (field-emission thrusters, ion engines, Hall-effect thrusters, resistojets and electric propulsion components) and cold-gas systems and is currently extended to chemical propulsion and aerothermodynamics activities.

The EPL activities evolve in the direction of supporting in particular Micro-thrust propulsion applications to ESA missions, mid and high-power electric propulsion for Exploration Missions and thruster-spacecraft interactions analysis with plume diagnostics for future Telecommunication and scientific spacecraft.

References

[1]R. Blott, D. Robinson, S.Gabriel, " Verification –Electric propulsion's Achilles Heel », IEPC-2001-062, 32rd International Electric Propulsion Conference, Wiesbaden, Germany, September 11-15, 2011.

[2]D. Di Cara, J. Gonzalez del Amo, A. Bulit, "Electric Propulsion testing: ESA propulsion Laboratory experience", 4th Russian-German Conference on EP & application.

[3]D. Di Cara et al, "Experimental validation of RIT Micro-Propulsion Subsystem performance, IEPC-2013-90, 33rd International Electric Propulsion Conference, Washington, D.C., USA, October 6 – 10, 2013.

[4]H.J. Leiter, D. Feili, B. Lotz, M. Tartz, H. Neumann, D. Di Cara, "Design, Development and Test of the RIT-µX mini-ion engine System", IEPC-2009-179, 31rd International Electric Propulsion Conference, Ann Arbor, Michigan, USA, September 20-– 24, 2009.

[5]A. Poli et al, "RIT micropropulsion system on Lisa PathFinder », IEPC-2011-325, 32rd International Electric Propulsion Conference, Wiesbaden, Germany, September 11-15, 2011.

[6]H.J. Leiter et al, "RIT-22 Ion Engine Development- Endurance Test and Life prediction", 42th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, AIAA 2006-4667, 9-12 July 2006, Sacramento, California, USA.

[7]L. Paita, "Surface electrical resistivity of randomly cesium contaminated FEEP ceramic", Space Propulsion Conference, Paper 2365865, Bordeaux, France, May 2012.

[8]C. Ducci, D. Dignami, P. Rosetti, M. Andreanucci, V. Vial, " HT100: Cathode coupling test and endurance", Space Propulsion Conference, Paper 2355348, Bordeaux, France, May 2012.

[9]S. Mazouffre, G. Bourgeois, K. Dannenmayer, A. Lejeune, "Ionization and acceleration processes in a small, variable channel width, permanent magnet Hall thruster", J. Phys. D: Appl. Physics 45, 185203 (2012).

[10] A. Passaro et al, "Development and Test of XR-150, a New High-Thrust 100 W Resistojet", IEPC-2013-219, 33rd International Electric Propulsion Conference, Washington, D.C., USA, October 6 – 10, 2013.

[11]J.R. Anderson, J.K. Ziemer, A. Bulit, "Cesium exposure test of the colloid micro-Newton thruster for the LISA PathFinder Mission", 48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, AIAA 2012-4293, 30 July- 01 August, Atlanta, Georgia, USA.

[12] A. Reissner, "Development and Verification of a microNewton thrust balance for High Voltage Electric Propulsion Systems", IEPC-2013-208, 33rd International Electric Propulsion Conference, Washington, D.C., USA, October 6 – 10, 2013.

[13]J. Perez Luna, C.H. Edwards, J. Gonzalez Del Amo, B. Hughes, "Development and Status of the ESA Micro-Newton thrust balance", IEPC-2011-011, 32rd International Electric Propulsion Conference, Wiesbaden, Germany, September 11-15, 2011.

[14]M. Wartelski et al, "The assessment of Interaction between Spacecraft and Electric Propulsion Systems project", IEPC-2011-028, 32rd International Electric Propulsion Conference, Wiesbaden, Germany, September 11-15, 2011.

[15]G. Matticari et al, " Modular Multi-application Electric Propulsion Diagnostic package (MM_EPDP) for advanced characterization of the Electric Propulsion- spacecraft interactions" , Space Propulsion Conference 2012, Paper 2357175, Bordeaux, France, 2012.