ESA Propulsion Lab at ESTEC

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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 at ESTEC in the spacecraft propulsion testing field. The EPL 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.

When applicable, the EPL also provides technical advice and support to external organisations for subjects related to propulsion testing and test facilities.

A laboratory dedicated to electric propulsion exists at ESTEC since early 1980s. In the last years, the activities of the laboratory, under project request, have been expanded to chemical propulsion (cold gas and other non-toxic propellants). During 2004, EPL has obtained dual ISO 17025 accreditation and ISO 9001 certification. In 2007 the EPL changed its physical location and several tests were performed in order to validate the correct functioning of the facilities

This paper will describe the EPL organisation, facilities and activities after the physical relocation.

Nomenclature

EPL	=	ESA Propulsion Lab
LP	=	Langmuir Probe
RPA	=	Retarding Potential Analyser
FC	=	Faraday Cup
FEEP	=	Field Emission Electric Propulsion

I. Introduction

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When applicable, the EPL also provides technical advice and support to external organizations for subjects related to propulsion testing and test facilities.
This paper will describe the EPL organization, facilities and activities.

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II. ESA Propulsion Lab (EPL)

A. EPL role and main interests

The testing of propulsion systems requires facilities capable to simulate vacuum conditions and designed "ad hoc" for this scope. In some cases such as electric propulsion thrusters the vacuum conditions required are very demanding (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 propulsion thrusters in the last decades. Lately, this lab has expanded its field of application to cold gas and other green chemical thrusters. Components validation tests are also an important activity in the EPL.

ESA projects are currently making a good use of the EPL, exploring its capabilities in terms of testing facilities and propulsion expertise coming from the Propulsion and Aerothermodynamics Division personnel.

EPL does not compete with European industries. Furthermore, EPL is a reference for all the propulsion companies in Europe and provide them with support in case it is required. A clear example of this point is the involvement of the EPL in the preparation of the network of electric propulsion facilities put in place in the last two years. This network will allow customers to change testing facilities in case a logistic or technical problem arises, minimising the schedule and cost impact in the project. To achieve this, a coordinated effort among the industry bodies and ESA is being carried out. The EPL is a reference for all the industrial participants in the field of standardization and procedures definition and contributes actively to propose alternative solutions to the problems found in this field.

The EPL provides an independent performance assessment of space propulsion technology and is able to provide quick answer to specific questions from ESA projects. The EPL is supporting the European Aerospace industry and research centres by inviting external organisations to test new technologies. The EPL is the reference for standardisation of testing methods and tools.

B. EPL Activities

The EPL supplies services to ESA projects requiring a first independent and fast assessment. Furthermore, the EPL enables a fast access to qualification tests that are long and expensive in nature.

Some ESA internal customers are:

- Lisa-pathfinder (FEEP and cold gas microthrusters)
- Cryosat (milli-Newton cold gas thrusters)
- GALILEO (cold gas thrusters)
- Microscope (FEEP microthrusters)
- Small GEO (cold gas thrusters)

The EPL dedicates 80 % of its resources to respond to customers needs and 20% to internal research, hands-on and training. The activities carried out at the EPL are charged to programmes and research and development programmes.

EPL may also supply services to any external customer due to the quality system that has been set up at ESA in the frame of an accreditation process.

The main tasks of the EPL laboratory are:

- Fast and independent technical assessment of propulsion technologies required for ESA projects, including possible failures assessments.
- Qualification by means of endurance tests.
- Internal research and hands-on of ESA staff.
- Training of ESA personnel.

The ESA propulsion Laboratory in the past has hosted qualification tests such as the lifetime test of the RIT ion engine that last 22000 hours. A facility of this type occupied for a long time is an investment that could not be done at that time by a single entity. ESA provided this opportunity to the Artemis project.

Research and development on FEEPs was also done at the Electric Propulsion Lab and this work was the reference for all the companies involved in this field. Nowadays, the work performed in FEEP has helped the ESA projects (LISA pathfinder, LISA, Darwin, GAIA, GOCE, etc.) to identify the critical areas of this technology and the way to proceed to solve the technology issues in an independent manner [1].

The ESA propulsion laboratory has several activities on testing of chemical propulsion systems such as cold gas thrusters. The work performed for cold gas microthrusters will help projects such as Gaia, Cryosat, Small GEO, etc.to find out the best propulsion candidate.

The EPL has changed physically its location in 2007 at ESTEC. This event was the perfect moment to plan for new investments and organise the best way to use the facilities and resources required to provide the best service to the internal customers already identified and possible new ones. New vibration suppression mechanisms present now at the lab allow to perform direct measurements of microNewton levels assessing the real thrust noise at these low levels inside the EPL vacuum chambers. Furthermore high power electric propulsion thrusters will be tested in the new location due to the availability of upgraded facilities.

One of the major perception challenges faced by EP is the potential interactions of the energetic plasma with the spacecraft. This was a concern for SS/L which uses EP for NSSK. The plume of the thruster impinges on the spacecraft solar arrays which are mounted on the north and south panels. This causes the solar array anti reflective coating to be eroded from the cell cover glass over the course of the mission. Predictions of solar array degradation due to EP plume impingement were made to size the solar arrays for EOL requirements and, after nearly four years on-orbit, solar array performance tracks these predictions. Up to date the models used to assess the possible spacecraft thruster interactions are validated with ground data. Some customers require more confidence on the results which can come from additional validation of such models with flight data. This issue has been recognized in Europe with a special effort to incorporate plasma diagnostics into telecommunication satellites. Validation of ground tests with the flight data will continue to demonstrate that these issues are understood and can be addressed. EPL has a leader position in this kind of activities by hosting specific tests on this subject in the next four years.

C. EPL Organisation

The laboratory is managed by the EPL manager assisted by the EPL infrastructure manager. An external company provides support for the maintenance of the EPL at weekly basis.

In case a specific support in the mechanical or electric domains is needed, ESA staff from other sections is required to work at the EPL.

The operation, maintenance and procurement are under the monitoring of the Head of the Propulsion and Aerothermodynamics division.

The justification for investments is performed by a group of people involved in the normal operation of the EPL (EPL manager, Head of the Electric Propulsion Section and the head of the Propulsion and Aerothermodynamics Division). These people have periodically meetings (steering board meetings) with the customers to design the strategy and the investments of the EPL.

ESA Mechanical department has just finalised an accreditation and certification process carried out by the Dutch Accreditation Council (RvA). Dual ISO 17025 accreditation and ISO 9001 certification processes have been obtained in 2004 by the EPL and validated through internal and external audits until 2009. Therefore, the procedures and outputs of the EPL are exposed to the quality requirements of the accreditation body.

The EPL personnel have implemented all the required procedures during the test plans, procedures and reporting preparation.

The EPL areas that required investment are: Vacuum facilities; Diagnostic packages; Data Acquisition systems and Quality issues (procedures, instrument calibration, etc.).

D. EPL Description

Figure 1. ESA propulsion laboratory cleanroom

The main features of EPL are: Certification ISO9001 (Quality Management); Accreditation ISO17025 (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; 7x test facilities dedicated to space propulsion testing (Vacuum chamber re-creating space environment with pressure down to 10^{-12} Atm. Beam target reducing the on-ground testing disturbances, High-speed High-resolution data acquisition systems; Calibrated commercial measurement instruments (Various electronic equipment from 1microV/1nA to 35 000V/20A), 3x Mass spectrometers for residual gas analysis; Customized measurement instruments with clear chain of calibration (5x balances for thrust from MicroNewton to Newton, 2x Beam diagnostics for beam divergence and energy distribution).

1. Vacuum chambers:

EPL vacuum chambers are state-of-the-art test facilities specially tuned for propulsion testing. Driver requirements are low contamination pumping system, ultimate background pressure, maximum pumping speed and reliability. The Corona test facility (see picture in Fig.2) is the most achieved EPL vacuum chamber which features:

- Low leak rate vessel < 10^{-4} mbar.l/s
- Oil-free pumping system
- Redundant pumps controlled by automatic system
- IR lamps for warming up internals walls and increasing outgassing (bake-out)
- Ultimate background pressure 10^{-8} mbar
- Pumping speed 80,000 L/s (Xe) allowing operational pressure < 10^{-4} mbar at 5 mg/s (Xe)
- Auxiliary chamber for thruster integration with movable platform
- Liquid Nitrogen-cooled beam target covered with graphite for low back-sputtering rate

Figure 2. EPL Corona Test Facility

The Corona test facility was used since 2005 for testing the Helicon Double Layer thruster (HDLT)[4], the Dual Grid Four Grids ion engine (DS4G)[5], the RIT-4 grids-ion engine, the 15cm Giessen Ion Source (GIS-15) and the mHET. The characteristics of all EPL vacuum chambers are reported in Table 1.

Table 1. EPL Vacuum Chambers characteristics

		Vacuum chamber						
		#1 FEEP	**#2 Galileo**	**#3 Gigant**	**#4 Corona**	**#5 Electron**	**#6 MicroNewton**	**#7 SPF**
Main chamber dimensions [m]		Ø0.8 x 1.3	Ø1 x 1.2	Ø1.6 x 2.5	Ø2 x 5	Ø0.8 x 0.5	Ø0.5 x 0.65	Ø2 x 4
Auxiliary chamber dimensions [m]		Ø0.3 x 3	0	Ø0.4 x 0.8	Ø1 x 1.2	0	0	0
Pumps	**Scroll**	0	0	1x	3x	1x	1x	1x
	Rotary	1x	1x	1x	0	0	0	0
	Roots blower	1x	1x	1x	0	0	0	1x
	Turbo	1x	1x	2x	3x	1x	1x	1x
	Cryogenic pump	3x	1x	2x	1x	0	0	0
	Cryogenic head	0	2x	4x	4x	0	0	2x
	Ion pump	0	0	0	0	0	1x	0
Pumping speed [L/s]		5,000 (N_2)	23,600 (Xe)	53,400 (Xe)	80,000 (Xe)	260 (N_2)	500 (N_2)	25,000 (Xe)
Beam target		No	No	Yes	Yes	No	No	No
Bake-out system		Yes	Yes	Yes	Yes	No	No	No

2. Thrust balances:

Thrust is one of the primary measurements for which EPL is accredited according to the ISO17025 standard. Specific measurement procedures for each instrument reported in Table 2 have been developed and validated through internal R&D activities on known thrusters. A clear chain of calibration of the measurement to international standard (ISO or IEC) is essential to the calculation of an uncertainty budget that EPL can provide when the certification of a measurement is requested. All sources of disturbances must be characterized during dedicated preliminary tests repeated for every thruster[2,3]. Fig.3 show two of the balances at EPL.

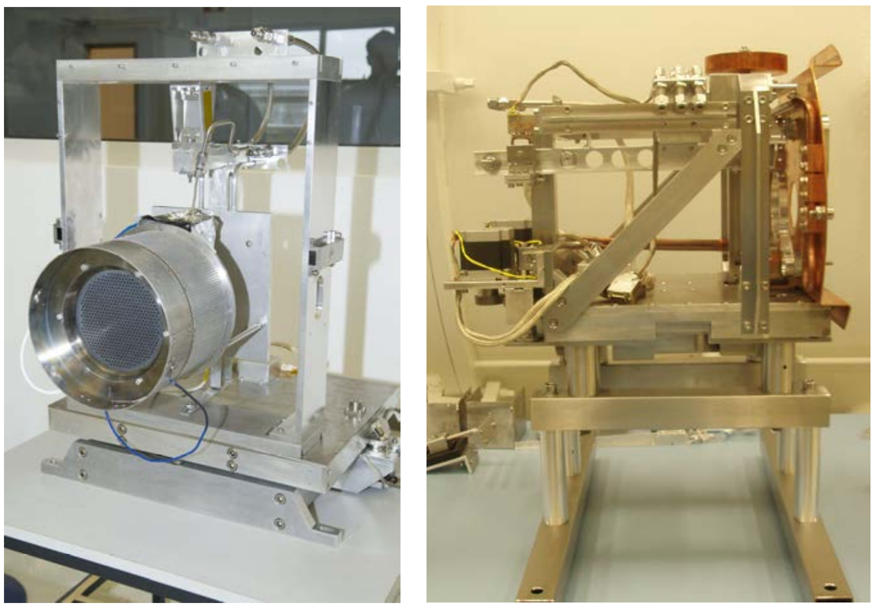

Figure 4. a) 1-axis optical thrust stand with GIS-15 and b) Low thrust balance

Table 2. EPL Thrust balances

	Range	**Uncertainty (best practice)**	**Resolution**	**Description**
Alta 1-axis optical thrust stand	5-500 mN	±2 mN	Variable	Inversed pendulum with optical strain gauges
Alta Low thrust balance	0.2-10 mN	±0.2 mN	Variable	Inversed pendulum with Laser displacement probe
Mettler-Toledo AX504	500 g ≡ 5 N	±10 μN	0.1 mg ≡ 1 μN	Modified commercial load-cell
Mettler-Toledo XP2004S	2.3 kg ≡ 23 N	±10 μN	0.1 mg ≡ 1 μN	Modified commercial load-cell
NPL micro-thrust balance	1 μN-1 mN	±0.1 μN	0.1 μN	Null-force folded pendulum (under development)

3. Beam diagnostics:

Thruster plume characterization is a critical measurement for electric propulsion thruster. EPL has been performing such a measurement using various electrostatic probes such as Faraday cups or Langmuir probe since the foundation of the laboratory. However, in an effort to standardize the measurement method, EPL has adopted a common design for the beam diagnostics:

- The Faraday cup is used for beam current density; the collector is biased slightly positively to limit secondary electrons to disturb the measurement while the shell is biased negatively to repel the electrons. Typically, the probes are moved in space to map the intensity of the plume and determine the divergence.
- The Retarding Potential Analyzer (RPA) is used for ions energy analysis; the design is similar to a Faraday cup by with a grids system (up to 3x at EPL) repels the ions with a threshold energy. Hence, ions energy distribution is obtained.
- The Langmuir probe is used to determine plasma parameters; single filament and triple filaments probes are used at EPL. The latest design allows instantaneous measurement of the plasma potential without having the need to sweep the voltage applied to the probe.

All the probes are usually installed on a remote-controlled movable rack which allows mapping the plume in 2 or even 3 dimensions (see pictures in Fig.4). EPL has raised the challenge of making accredited the beam diagnostics measurements. In order to achieve this objective (and others), a working group dedicated to the standardization of EP testing was created.

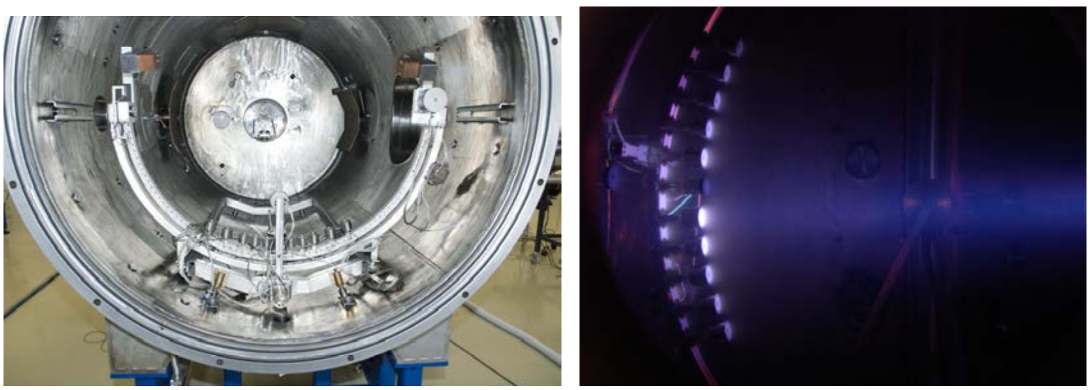

Figure 5. a) Gigant diagnostics arm and b) Corona diagnostics arm

E. Post-relocation validation activities

In 2007, EPL was relocated within ESTEC. In addition of the vacuum facilities, the relocation implied the removal of the measurement instruments from the test facilities while they were being transported (for safety). It was acknowledged that the measurement instruments would have to be tested for acceptance after they had been re-installed in the test facilities. In addition, after such harsh modification of environment, it was an ISO implicit requirement to demonstrate that the measurement procedures were still applicable and that the measurement capabilities were sustained.

With respect to ISO17025, EPL is accredited for certifying the following direct and indirect measurements in the associated ranges:

- Force; 1µN-500mN
- Electrical power; 0.1W-2kW
- Mass flow; 0.1µg/s-300mg/s

Five tests have been performed for validating the accredited measurement procedures of EPL after relocation and are listed in Table 3.

Table 3. Validation tests matrix

(GIS-15=15 cm Giessen ion source; In FEEP SEM=Indium FEEP single emitter module; OCT=orbit control thruster; MPT=micro proportional thruster; FE NA=field emission neutralizer assembly)

	Measurement				
	Thruster		Mass flow rate		Electrical Power
	Direct	Indirect	Direct	Indirect	
GIES-15	×	×	×	×	×
In FEEP SEM		×		×	×
CRYOSAT OCT	×		×		
MPT	×				
FE NA					×

The ISO17025 external audit performed on November 29th 2007 confirmed the accredited status of the EPL based on the testing activities. The ESA propulsion laboratory was inaugurated on April 8th 2008.

III. Conclusion

The EPL is now a certified and accredited laboratory that gives support to ESA projects and European industry in the development and qualification of EP products that are flying in ESA projects such as Artemis, Smart-1, GOCE, Cryosat,, Lisa-pathfinder or Small GEO.

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