# ESA Propulsion Laboratory at ESTEC

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**Abstract:** **Electric and/or chemical propulsion systems are necessary for any spacecraft application. 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 Center (ESTEC) in Noordwijk, The Netherlands. 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. This paper will describe the EPL organisation, facilities and the last activities performed.**

## Introduction

SPACECRAFT propulsion systems are necessary for any application. 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[1]. Full characterisation, qualification, acceptance and plume interaction tests are mandatory in the full assessment of these technologies.

The ESA Propulsion Laboratory (EPL)[2] is an operational facility in the spacecraft propulsion testing field located at the European Space Research and Technology Center (ESTEC) in Noordwijk, The Netherlands. 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.

Since 2004, EPL holds ISO 17025 accreditation. The EPL can perform accredited mass-flow, thrust (direct and indirect) and electrical power measurements for electric and cold-gas thrusters and components. It also offers support to ESA projects and develops technology required for ESA in the field of propulsion. When applicable, the EPL also provides technical advice and support to external organisations for subjects related to propulsion testing and test facilities.

In the last years, the activities of the laboratory, under project request, have been focused on testing electric propulsion system below 2 kW. EPL activities also expanded to low thrust measurements (micro-Newton balance), chemical propulsion (cold-gas and other non-toxic propellants), propulsion components (waterhammer tests) and fluid dynamics (sloshing bench).

This paper will describe the EPL organisation, facilities and the last activities performed.

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## I. Activities of the ESA Propulsion Laboratory

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, SmallGEO and EUCLID have been or are currently using EPL capabilities. For example, a subsystem coupling test with the Mini-Ion Engine RIT-µX is planned to be conducted in June-July 2015 in the GIGANT Vacuum Facility at the EPL in the frame of the development activity of the RIT-µX micropropulsion subsystem for future space missions. This test will check the coupling of each of the equipment composing the electric propulsion subsystem. The test will include the RIT- µX thruster from Airbus Defence and Space, a EM neutralizer developed by Thales Italy and transferred to Selex-ES, a PPU developed by Selex-ES and a µFCU developed by AST-GmbH. 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[3]. 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[4]. Several tests devoted to the development of new engines such as mini-ion thrusters and mini-Hall Effect thrusters[5,6] 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 Sitael S.p.A[7] were tested in the EPL to measure their thrust. Recently, a 1 kW arcjet thruster developed by Sitael S.p.A. has been tested in the EPL to evaluate its performance and lifetime using both Argon and Helium as propellants. A flow regulator with the capability to act as pressure reducer and developed by Selex-ES was tested in closed loop with a mini-HET to demonstrate its single stage operation principle.

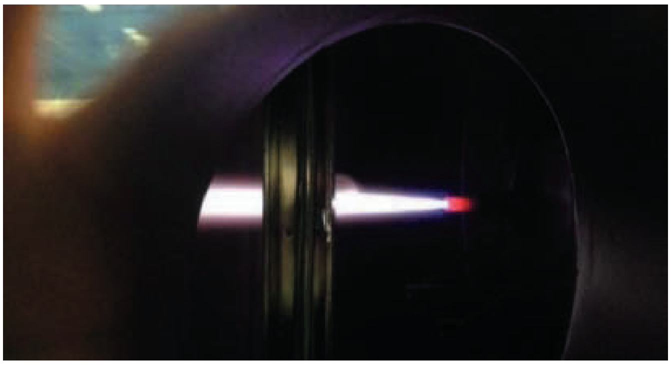

**Figure 1. Sitael S.p.A. AT-1k arcjet firing in SPF Vacuum Facility in SPF**

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. For example, in 2014 a 500W HET first prototype designed to be operated with Krypton and developed by IPPLM, Poland, was characterized in the EPL. 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. 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.

In parallel, the EPL has a continuous process to improve its capabilities by the addition of new diagnostic equipment. For example, the ESA Micro-Newton Thrust Balance[8] was successfully accredited to perform ISO17025 certified direct thrust measurements of a cold-gas thruster in steady-state conditions. The knowledge acquired in this activity was then used to verify the correct functioning of a FOTEC developed micro-Newton thrust balance[9]. In addition, several plasma diagnostic probes have been incorporated to the already existing, including an ExB probe developed by ICARE and an internally developed single Langmuir Probe.

The EPL is carrying out a process to expand its activities towards generic propulsion activities. A flow rig was commissioned in 2014 to evaluate propulsion components in waterhammer tests. In this frame, a set of 3D-printed injectors were tested on this equipment. Additionally, activities to study of the sloshing effect in fuel tanks have been performed in a test bench specifically designed for this.

## II. Organisation of the ESA Propulsion Laboratory

The EPL is managed by the EPL manager with the support of the EPL infrastructure and quality manager. The EPL manager 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. This board assesses the work performed within one year and design the strategy of EPL in investments and activities for the next year. For every test performed, a test team is formed. A senior 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.

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

## III. Facilities and Capabilities of the ESA Propulsion Laboratory

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).

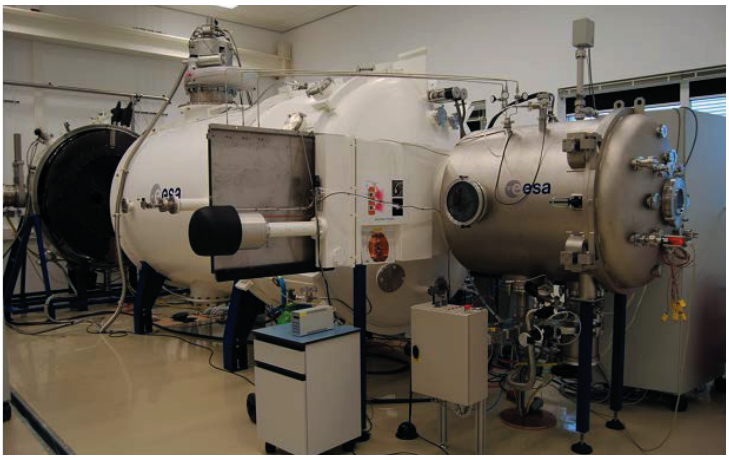

**Figure 2. CORONA Vacuum Facility in EPL**

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:

- 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 background noise isolation
- 7 vacuum facilities dedicated to space propulsion testing
    - o Vacuum chamber reproducing space environment with pressure down to 10-9 mbar
    - o Beam target and diffuser reducing on-ground testing disturbances

- o High speed high resolution data acquisition systems
- 1 flow bench (accepted for water-hammer tests)
- 1 sloshing bench
- Calibrated commercial measurement instruments
  - o Various electronic equipment for measurements from 1 μV/1 nA to 35,000 V / 20 A
  - o Mass spectrometers for residual gas analysis
  - o Infrared Thermocamera
  - o Pyrometer
- Customized measurement instruments with chain of calibration
  - o 5 thrust balances for thrust measurement from microNewton to Newton ranges
  - o 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 Sitael 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, and more recently, developed an ExB probe and its electronics for the measurement of the ion velocity distribution function; the University of Stuttgart is developing a Langmuir Probe. Nevertheless the EPL has independent capabilities to carry out this kind of activities: internally designed single-Langmuir probe and emissive probes are being successfully used in the laboratory to determine the plasma parameters in a Hall Effect Thruster plume. In 2014, the EPL carried out an activity to assess the calibration of several plasma diagnostic probes with a HET to path the way towards the standardisation of EP testing.

A microNewton thrust balance 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 was recently accredited to perform ISO 17025 accredited measurement for direct thrust measurement in steady-state conditions. This is the first instrument worldwide to be accredited to ISO17025 standards which can measure down to the micro-Newton of direct thrust measurement with an uncertainty of ± 1 μN.

**Figure 3. ESA Micro-Newton Thruster assembly**

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. EPL has also demonstrated its capabilities to perform spacecraft-thruster interaction tests in the past. Performance of components for chemical propulsion may also be measured. The last few years a water flow rig bench 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. The bench was upgraded and commissioned in 2014 to allow water-hammer experiments to measure pressure peaks due to fast opening/closing of valves.


**Figure 4. EPL Flow Rig Bench**

In the area of aerothermodynamics, a sloshing bench (Figure 5) was developed in collaboration with NUMA (Ireland). In the first phase, this is being 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. It has a high-resolution high-speed camera installed on it to measure the oscillations of the fluid.

**Figure 5. EPL sloshing bench**

Recently, the EPL acquired a Magnetic Field Mapping System, developed by Sitael SpA that allows to perform 3D measurements of the magnetic field generated by a generic item, typically HET permanent magnets.

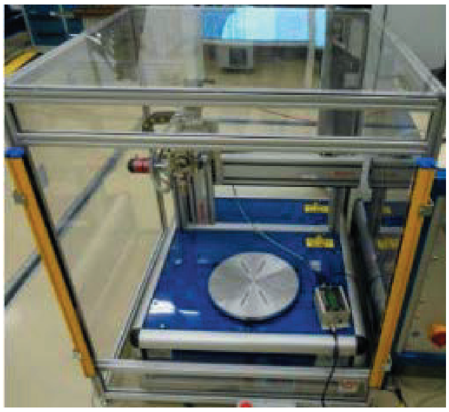

**Figure 6. EPL Magnetic Field Mapper system**

The EPL is evolving along with the requirements of future Telecommunication and Scientific missions which are in the preliminary phases. It is expected that spacecrafts required thrusters will shift towards the 5kW range for both Ion and Hall-Effect Thrusters (NeoSAT, ELECTRA). The first step EPL will conduct to adapt to this change is to upgrade the CORONA facility with a new $LN_2$ shroud and to increase its pumping speed capability to be able to test EP thrusters in the aforementioned power range. In addition, the EPL is already conducting activities to upgrade the accredited Micro-Newton Thrust Balance in order to allow the accredited direct thrust measurement of EP thrusters in the micro-Newton range and to measure thrust noise of larger thrusters. Activities are focused on minimising the background vibration sensed by the balance, increasing the resolution of the measurement system, and compensating the thermal effects of the EP devices on the signal.

## IV. Conclusions

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, arcjets 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 and Telecommunication Missions and thruster-spacecraft interactions analysis with plume diagnostics for future platforms and scientific spacecraft

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