ESA Propulsion Laboratory at ESTEC

IEPC-2019-A-773

Presented at the 36th International Electric Propulsion Conference,
Vienna, Austria
September 16 – 20, 2019

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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. New technologies are evolving the requirements rapidly, and 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. New technologies such as CubeSat propulsion and very-high power EP are evolving the requirements rapidly, therefore 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.

The EPL holds and ISO 9001 certificate and can perform mass-flow, thrust (direct and indirect) and electrical power measurements for electric and cold-gas thrusters and components with in-house procedures that have demonstrated to be reliable and repeatable. 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 supporting the Bepi Colombo SEPS, improving TRL of small thrusters for future Science and Earth Observation missions, and testing

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the proof-of-concept of new ideas from European industry. EPL activities also expanded to testing of CubeSat Propulsion Systems, standardisation of Electric Propulsion Testing, chemical propulsion (miniaturised hot firing tests), propulsion components (green propellants compatibility) and fluid dynamics (sloshing bench).

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

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 Bepi Colombo, Lisa Pathfinder, M-ARGO, NGGM, GAIA and EUCLID, among others, have been or are currently using EPL capabilities. For example, a subsystem test with the Ion Engine T6 was conducted in June-August 2018 in the CORONA Vacuum Facility at the EPL in the frame of the launch phase of the Bepi Colombo mission. The test objective aimed at verifying the results achieved by the lifetime test conducted in parallel in QinetiQ facilities in Farnborough (UK). The EPL will continue the support of the Bepi Colombo mission as a potential test facility for the E2 phase of the mission (in-orbit support). 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 NGGM mission. Since several years, the EPL is providing support in testing several technologies that are available in Europe in order to provide a solid performance analysis to the mission.

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 Research Centers. In the last few years, R&D activities on miniaturised Ion-Engine technologies performed at the EPL helped all European companies and laboratories involved in this field. Several tests devoted to the development of new engines such as mini-Hall Effect thrusters that will be the baseline for constellations have been and will continue to be hosted by the laboratory. Many other miniaturised thrusters for their implementation in small satellites and were tested in the EPL to measure their performance (thruster and Isp), such as a miniaturised Resistojet from TNO. Recently, a 600W Helicon Plasma Thruster has been tested in the EPL to evaluate its performance using both Xenon and Argon as propellants.

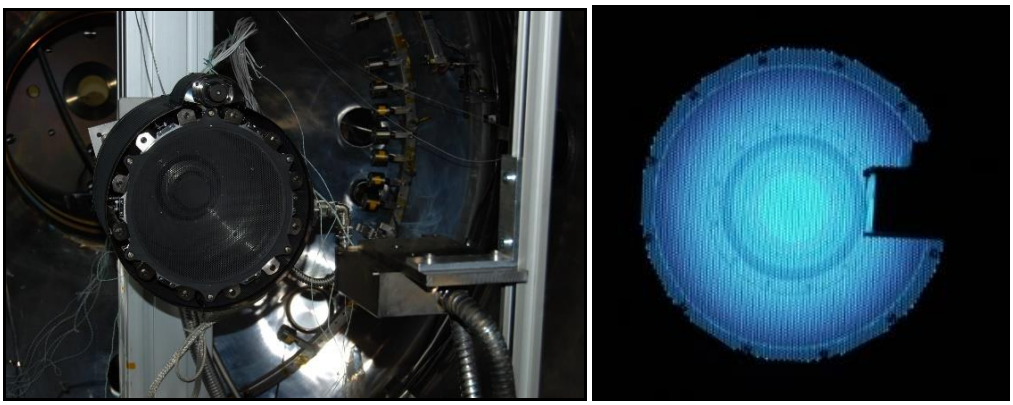

Figure 1. QinetiQ T6 Thruster firing test at the EPL

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 2019 a 6-DoF Cold-gas Thruster designed to be operated with Butane and developed by NanoSpace, Sweden, 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. A strong effort is now in place to implement a CubeSat Propulsion Test Bench that can be used by all the new technologies and concepts developed around Europe for this kind of application.

The EPL is carrying out a process to expand its activities towards generic propulsion activities. As example, a test is being prepared to perform a characterisation of a miniaturised bi-propellant thruster for CubeSat applications. In 2018, a facility was built within the laboratory to perform compatibility tests between tank materials and green propellants. In addition, the flow bench keeps being updated in line with the requirements from the industry, and was recently used by Airbus UK to qualify the fluidic system of the MTG spacecraft with respect to the requirements on high-pressure resilience.

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 Directorate of Technology, Engineering and Quality (TEC) to which the EPL belongs has passed an ISO 9001 certification process carried out by NQA. 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 cold 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).

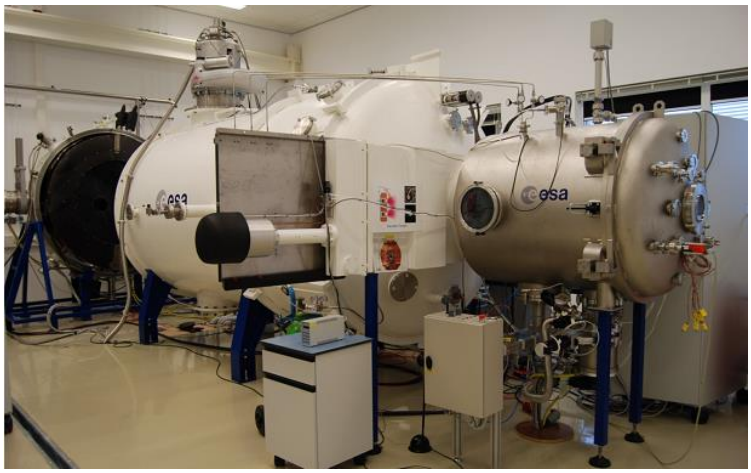

Figure 2. CORONA Vacuum Facility in EPL

The domain of competence of the EPL includes procedures for the direct and indirect measurements of thrust, mass flow and electrical power related to propulsion systems operation in specific ranges which have been extensively tested and proved reliable and repeatable.

Features of testing facilities at EPL:
- Certification of ISO 9001 (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
- 1 green propellant test 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. Currently, the EPL is performing an activity to assess the calibration of Faraday Probes with an Ion Engine to path the way towards the standardisation of EP testing.

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 green propellant test bench was commissioned in the EPL for assessing the compatibility between tank material and multiple new propellants. Tests with calibrated orifices (flow restrictors) were successfully performed allowing demonstrating the limitations of the bench.

Figure 3. EPL Flow Rig Bench

The EPL is evolving along with the requirements of future constellation and CubeSat missions which will be equipped with Electric Propulsion Systems. It is expected that thousands of spacecrafts will equip these systems, which will have a complete new set of requirements compared to traditional propulsion systems, specially regarding the cost. The first step EPL will conduct to adapt to this change is to upgrade the SPF facility with a new CubeSat Propulsion Test Bench. This tool will be used as a single-step qualification stage for any CubeSat Propulsion system.

In this area, a first prototype of the CubeSat Propulsion Test Bench was designed and manufactured by Politecnico di Torino. The system is based on a 6U CubeSat Platform and has the equivalent space of 2U for the allocation of a complete propulsion system. The platform includes a set of batteries as Electric Power Supply system, and a computer with a set of electrical and data interfaces that are used to control the Propulsion System. This platform is being updated with additional diagnostic systems, satellite simulator (for both Power and GNC) and the capability to feed both power and propellant from external supplies.

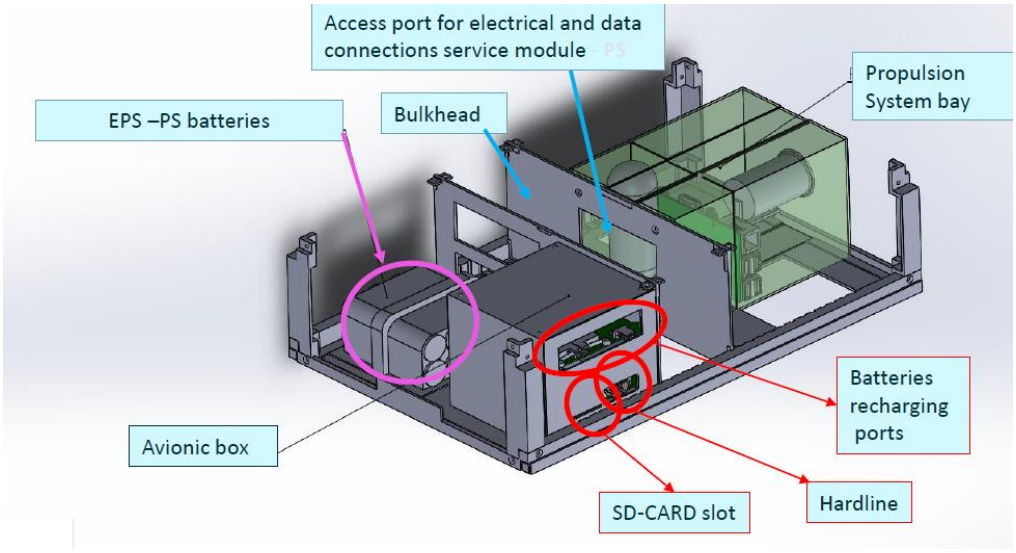

Figure 4. EPL CubeSat Propulsion Test Bench prototype

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 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 miniaturised chemical propulsion systems and components testing of elements of propulsion systems.

The EPL activities evolve in the direction of supporting in particular Micro-thrust propulsion applications to ESA missions, CubeSat and constellation Propulsion Systems, and 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. In addition, new equipment allows the EPL to conduct compatibility tests with Green Propellants.

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