Review of ESA Experimental Research Activities for Electric Propulsion

José Antonio Gonzalez del Amo
European Space Agency, ESTEC
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS

ABSTRACT

In the commercial telecommunication space arena, the strong competition among satellite manufacturers is a major driver for advancements in the area of Electric Propulsion (EP), where increasing better performance together with low prices are required. The use of Electric Propulsion will enable to use cheaper launchers or extend the life of current telecommunication spacecraft. Furthermore, new scientific and Earth observation missions dictate new challenging requirements for propulsion systems and components based on advanced technologies such as microNewton thrusters. Moreover, new interplanetary missions in the frame of exploration will require sophisticated propulsion systems to reach planets such as Mars and in some cases bring back to Earth samples from these planets. A future colonisation of Mars will require large cargo missions using Electric Propulsion.

ESA is currently involved in activities related to spacecraft electric propulsion, from the basic research and development of conventional and new concepts to the manufacturing, AIV and flight control of the propulsion subsystems of several European satellites. The exploitation of the flight experience is also an important activity at ESA which will help mission designers to implement the lessons learnt to the development of these new propulsion systems. ESA missions such as GOCE, Smart-1 and Artemis have paved the way for the use of electric propulsion in future ESA missions: Lisa-pathfinder, Bepi Colombo, Small GEO, Alphabus, LISA, etc.

This paper will evaluate the current and future challenges of the electric propulsion field at ESA. The status of the technology, the current and future applications will be also presented and the experimental research activities that are carried out at the ESA Propulsion Lab (EPL) at ESTEC in this domain.

INTRODUCTION

The thrusters of Electric Propulsion systems accelerate the propellant ions to velocities of tens of kilometers per second making it a propulsion option that is well suited for energetic deep-space missions as well as attitude control and orbit topping for near-Earth spacecraft. The Electric Thrusters can be divided in four types:

- Electrostatic engines: Ion Engines, Field Emission Electric Propulsion (FEEP), Colloids
- Electromagnetic/Electrostatic engines: Hall Effect Thrusters (HET), Highly Efficiency Multistage Plasma Thrusters (HEMPT)
- Electromagnetic Engines: Magneto Plasma Dynamics Thrusters (MPD), Pulsed Plasma Thrusters (PPT).
- Electrothermal Thrusters (Arcjets, Resistojets).

The main characteristics of the Electric Propulsion thrusters are reported in Table 1.

Table 1: Characteristics of Electric Propulsion thrusters.

	Electrothermal	Electrostatic		Electromagnetic
Mechanism	Gas heated via resistance element or arc discharge and expanded through nozzle	Ion electrostatically accelerated.		Plasma accelerated via interaction of current and magnetic field.
Concept	Resistojets Arcjets	Ion Engines FEEP Colloids	Plasma Thrusters	
			HET HEMPT	MPD PPT
Power (kW)	0.1 – 2	0.02-5	0.1-5	10-100
Specific Impulse (sec)	100-600	3000-4000	1000-2500	>3000 sec

The advantages of Electric Propulsion with respect to the Chemical Propulsion is the high specific impulse that implies a significant saving in propellant mass, and the capability of a very good controllability due to the possibility of generating very low thrust and very small impulse bit.

On the other hand, to obtain high specific impulses, the Electric Propulsion System needs a high power to thrust ratio, meaning in some cases power systems capable to generate several kWs. This could imply:

- Significant increase of the mass of solar arrays and batteries
- Increase of the complexity the power distribution system.

However in case the satellites require high power to operate their payload, the power system can be used by the electric propulsion system when is not used by the payload (for example in orbit topping operations for going from a parking orbit to a final operational orbit saving huge amounts of propellant in this process).

TELECOMMUNICATION MISSIONS

In Europe, electric propulsion development, for orbit raising and control, has focussed on both gridded and Hall effect thrusters; with France developing the Hall effect PPS-1350, Germany the RIT gridded ion thruster, and the UK the electron bombardment gridded ion thruster (T5 and T6). The first ESA mission to employ electric propulsion in flight was Eureca, launched in 1992, which included a RIT type ion thruster for test purposes. Later, the Artemis mission was launched, including two types of gridded ion thruster, the German RIT and the UK electron-bombardment ion thruster (T5). These were originally designed to be used only for north south station keeping, but when a launcher underperformance left the spacecraft stranded in a low orbit, the mission was innovatively re-designed and saved by the combined use of the hydrazine and electric propulsion subsystems. Without the use of the EP subsystem the spacecraft would have been unable to reach its operational orbit[1].

Electric Propulsion (EP) systems have demonstrated good performance in orbit. The main challenge is now competitiveness. The cost of the overall system (thrusters, power supply and mechanism) must be competitive against the extra price on launcher or extension of bipropellant tanks. Today the launcher market pricing structure by steps, and the too high price of available European EP systems are such that European Telecom Primes have to stay with extended Bi Propellant system, up to the moment when the competition on Launcher is too small (over 6 Ton), and then EP is used. Consequently EP today is used as an optional add-on package. This currently results in limited opportunities (few per year), but might enlarge in the future as payload increase Power and Mass. It is worth noticing that US primes seem to have different approaches. Indeed LM with Dual Mode used Arcjets, and now has moved to add on Hall Effect Thrusters (BPT 4000), Loral is using SPT 100 add on Package as European do, and is now thinking to use Hall Effect Thrusters (SPT 140), Boeing currently use Gridded Ion Engines (XIPS) on 702B platforms only on high end. In US several Hall Effect Thrusters have been qualified, equivalent to SPT100, and SPT 140 (Aerojet) [1]. The use of EP in Transfer/Orbit Top up (final injection in GEO) is still an issue due to the requested long time for an efficient impact, resulting in non acceptable duration for operational missions (optimization can be performed for reignitable launcher). However, for new platforms designed for specific missions, Hall Effect Thrusters can be used for primary propulsion (ex: ConeXpress CX2) and allow both orbit transfer in acceptable time and station keeping.

In view of the increasing mass and mission duration for the new GEO platforms, the requirements on the total impulse to be provided by the electric propulsion system are constantly increasing. As a result, the currently qualified thrusters, such as the SPT-100, will not be able in the near future to fulfil the total impulse specification for the future commercial missions. It is for this reason that the major European producers of electric thrusters initiated development programmes to extend the operational capability of the current Hall-effect thrusters (PPS-1350)

Further to work on the evolution versions of their current platforms, Thales-ALCATEL and ASTRIUM have joined the efforts to design and develop together the next generation of European GEO platforms, which is planned to be offered on the market in the near future. This new platform, called @BUS, will offer a very high power payload capability (up to 12 kW in the short term and higher power in the long term) and will optimize the use of EP, because the EP operations will possibly be extended in the future to include other functions than NSSK, notably full or partial orbit transfer to the GEO orbit and other functions. New, high thrust EP systems are needed for this new platform and all the major European EP thruster suppliers are currently initiating these developments. In particular, SNECMA (F) is carrying out the development of a high thrust version of their PPS Hall-effect thruster, called PPS 5000, while QuinetiQ (UK) are involved in the development of new, high thrust gridded ion engines, the T6 thruster. Pre-development activities in the area of European high thrust EP systems for application on @BUS are being funded by ESA in the frame of the ARTES-8 programme. The PPS1350 has been selected as main candidate for the short term. For the @BUS evolution (up to 20 kW), the T6 could be a good candidate.

Small GEO (see Figure 1) satellites will be capable to carry a payload of around 300 kg in a spacecraft of less than 4000 kgr and fitting in SOYUZ. Hall Effect thrusters and HEMPT technologies will be in charge of performing attitude and orbit control.

Figure 1: Small GEO platform.

SCIENTIFIC MISSIONS

1. Interplannetary Exploration Missions: Smart-1 and Bepi Colombo

Replacing or augmenting chemical propulsion with electric thrusters as the primary propulsion system may introduce several benefits: Increase in net payload mass (enable missions otherwise impossible); Reduction in flight time with respect to mission based on chemical propulsion and complex gravity assisted operations (reduction in mission operation costs); Independence from launch window constraints, which are imposed by the classical gravity-assisted planetary fly-by operations (increase of the mission scientific objectives); Possibility to use small/medium launch vehicles (substantial launch cost savings).

Smart-1 demonstrated clearly all these advantages after a successful mission in space. Smart-1 mission has been the first of the European Space Agency's (ESA) Small Missions for Advanced Research in Technology (SMART) and was dedicated to testing new technologies, in preparation for ambitious future cornerstone missions such as Bepi-Colombo. SMART-1 was launched on September 27th 2003, as an auxiliary passenger on Ariane 5. The primary technology being demonstrated was solar electric primary propulsion, The Snecma PPS1350 Hall Effect Thruster. The Electric Propulsion Subsystem (EPS) was tasked with pushing Smart-1 from its Geostationary Transfer Orbit (GTO) starting point, to a polar orbit around the Moon.

Solar Electric Propulsion (SEP) has long held promise for numerous space applications, and over recent years has matured into flight proven hardware in both the commercial and exploration sectors. In comparison to conventional chemical propulsion, SEP spacecraft are characterised by high specific impulses, low thrust levels and long burn times. The large specific impulse gains effectively allow relatively small propellant fractions to provide very large impulses, not possible with chemical systems (e.g. on SMART-1, 82kg of propellant in a spacecraft of 370kg allowed a total ΔV of around 3.7 km/s to be delivered).

The ESA Cornerstone mission to the planet Mercury, BepiColombo, will make use of the ion propulsion system with high specific (>4200 sec) and high total impulse capability. Qinetiq has been selected to provide the T6 for this purpose (see Figure 2).

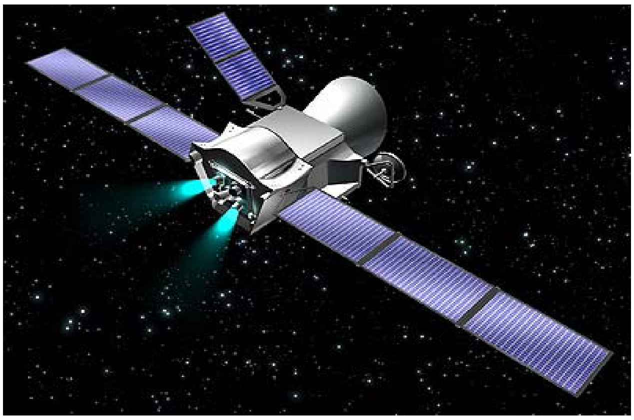

Figure 2: The Bepi Colombo Mission Concept.

The BepiColombo Solar Electric Propulsion Module will be propelled by a cluster of high-power (in the 5-6 kW range) gridded Ion thrusters, T6, providing a maximum thrust of 200 mN each. The system architecture philosophy will maintain one complete propulsion unit (Thruster, PPUs and FCU) in cold redundant status.

Once, this engine is developed for BepiColombo, the recurring cost of the engine will be reduced and other interplanetary missions requiring high delta-V will make use of this technology in the future.

2. High Precision Scientific Missions: Lisa-Pathfinder, LISA, Microscope

The Laser Interferometer Space Antenna (LISA) mission's goal is to detect gravitational waves, distortions of space-time occurring when a massive body is accelerated or disturbed. To achieve that goal the relative position of several solid blocks placed in different spacecraft, 5 million kilometers apart, will be constantly monitored with a high accuracy using laser-based techniques [2]. A gravitational wave passing through the spacecraft will cause these bodies to vibrate, changing the separations between them (Figure 3). But the changes will be so subtle that in order to perceive them the position of each satellite must be controlled up to the nanometer level. Also, scientists need to be completely confident that the vibrations of the solid blocks in each spacecraft are indeed caused by a gravitational wave and not by other phenomena, such as the solar wind.

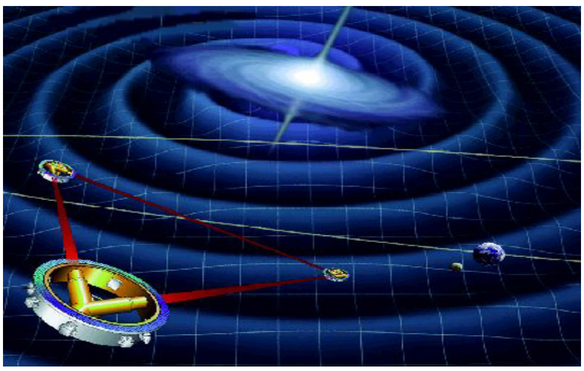

Figure 3: The LISA Mission Concept.

The success of the mission is based on the performance of such a sophisticated accelerometer concept, which must work under drag-free conditions. The drag-free control of the spacecraft will be provided by

FEEP thrusters. Higher thrust EP systems could be used for the orbit transfer phase of this mission. The control torques and forces for the attitude and drag-free control during the operational phase are given by the FEEP thrusters by providing a controlled thrust in the range of 1 to 100 µN, with a noise below 0.1 µN. LISA is envisaged as an ESA/NASA collaborative project. LISA is aimed at a launch in the 2013 time frame.

LISA relies on technologies that have never been tested in space, including the FEEP system, so LISA could be built without a previous space demonstration. This is the objective of the Lisa-pathfinder mission. Lisa-pathfinder is the technology demonstrator for LISA. Lisa-pathfinder will verify, among other things, the drag-free system, i.e. the accelerometers (inertial sensors) and the micronewton electric propulsion (FEEP, Colloid Thruster). The FEEP is designed to operate during the drag-free mode and AOCS functions (see Figure 4). Colloid thrusters are included to perform the drag-free mode with the DRS inertial sensor provided by NASA, added in parallel to the ESA inertial sensor.

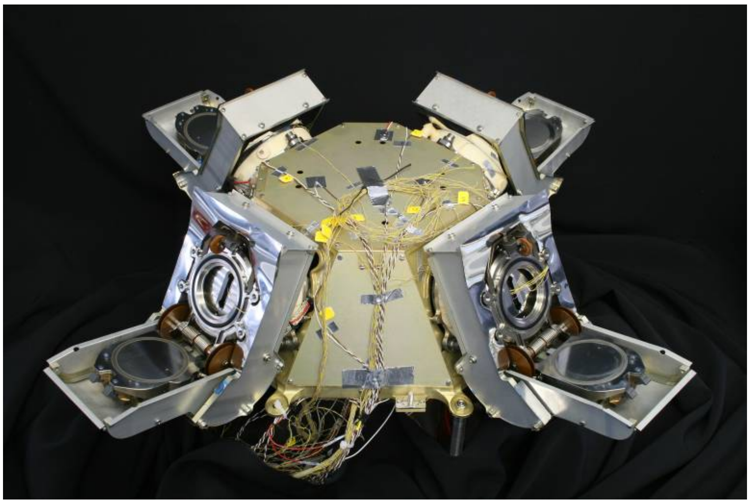

Figure 4: FEEP thrusters for LISA-Pathfinder Concept and___________ .

The scientific objective of MICROSCOPE is the verification of the Equivalence Principle between the inertial mass and the gravitational mass of two different materials, with a precision better than 10^{-15}, more than what it has been possible to verify on ground so far. This mission is funded by CNES and it is based on a standard CNES microsatellite bus. The sophisticated AOCS requirements for this mission could be fulfilled by a FEEP or a cold gas propulsion system. The Microscope Propulsion System will be provided by ESA, as a result of an ESA/CNES agreement.

The development of the FEEP system is vital to the ESA science programme. In order to have this technology ready to fly, an important effort is being dedicated to the characterization and lifetime of these thrusters. Two industries are currently developing two different concepts of FEEP: Alta (I) and AIT (A). Alta solution is the baseline and AIT solution is now a backup.

EARTH OBSERVATION

The main aim of the GOCE mission is to provide unique models of the Earth's gravity field and its geoid (reference equipotential surface) to high spatial resolution and accuracy. GOCE will also perform advance research in the field of steady-state ocean circulation, physics of the Earth's interior and leveling systems. The launch of the satellite took place in 2009. The GOCE satellite (see Figure 5) is a low-Earth orbiting spacecraft (275 km) that has a small cross section of approximately 1 m2, and be totally symmetrical to minimise the influence of external forces. The design configuration maximises the use of available volume under the launcher fairing by using fixed solar panels. There are no deployables or mechanisms to produce shocks. There is no sloshing effect as all the thruster propellant is gas. The actuators for orbit maintenance and along-track drag control are a pair of ion thrusters. The primary function of the ion engine on GOCE is to provide variable thrust for compensation of the drag force in flight direction throughout the satellite measurement phases. In addition the ion engine supports instrument calibration and satellite maintenance phases by providing sufficient thrust for orbit raise manoeuvres and atmospheric drag compensation [3].

Figure 5: The GOCE Spacecraft.

The Ion Propulsion Assembly (IPA) is made up of the following subsytems: the Ion Thruster assembly (ITA), the Ion Propulsion Control Unit (IPCU), the Proportional Xenon Feed Assembly (PXFA) and the Xenon Storage Tank (XST). The stringent requirements in terms of thrust range, noise and stability impose severe constraints on each of the subsystems of the IPA. The ITA is provided by QinetiQ (UK); Bradford Engineering (NL) has been appointed as the supplier for the PXFA and CRISA (E) is in charge of the IPCU. An endurance test of 5000 hrs has been performed successfully on this engine.

Another important initiative carried out by the Propulsion Division at ESA is the study of the possible applications of electric propulsion to future European Earth observation missions.. The post GOCE mission that is composed of two small satellites flying in formation in a very low orbit is considering the mini-ion engine from EADS and University of Giessen to compensate very small drag forces.

A special activity at ESA on flight data analysis of GOCE will be carried out during 2010 by QinetiQ.

EXPLORATION

Missions such as Mars Sample Return and Mars Next Landers will benefit of the use of electric propulsion systems for the transfer of such spacecraft to Mars. High power EP engines such as T6 (QinetiQ) and PPS 5000 (SNECMA) may be good candidates for these missions.

If we want to colonise Mars, it will necessary to bring cargo missions with all the required materials to build power reactors, habitats and all the goods required to maintain humans in Mars. One of the most efficient ways to perform cargo missions is by using electric propulsion as main propulsion system. The use of the high specific impulse of the electric propulsion systems will enable the use of current launchers which are already designed for commercial applications. In order to bring large cargo missions to Mars, it is necessary to create an orbital infrastructure around the Earth which could be used as a main station to refuel, change thrusters and power systems of spacecraft that could go and come from Mars to the Earth. High power EP systems in the range of 10 kW could be the first systems to be used by mission designers.

Later on as soon as nuclear power systems could be used in space, versions of higher power EP systems (> 50 kW) could be used.

FACILITIES

Test facilities and standarised test procedures are needed for a proper development and qualification of the electric propulsion systems. Networking of facilities and standardization of test methods and diagnostic techniques will be needed if Europe wants to optimize its resources in this important area. Furthermore, it is mandatory that the tests performed in different test facilities on the same engine provide congruent results, thanks to the use of consistent diagnostic methods and tools. This is especially complex when the thrust levels that have to be measured are in the order of micro-Newtons as is the case for missions such as LISA or GAIA. The possibility of cross-verification of European and non-European thrusters in different facilities world-wide is considered a possibility to speed-up the acceptability of electric propulsion on new missions.

MAIN CHALLENGES FOR EP SYSTEMS

The main challenges for Electric Propulsion (EP) system for near future are:

- Improving the access price to overall EP system, starting with Hall Effects Thrusters
- Increase competitiveness of Ion Engine, increase robustness (grid short circuit)
- Qualification of HEMPT, diversification of this technology to other thrust and specific impulse ranges, exploration of clustering capabilities
- Qualification of FEEP for Scientific missions, Earth Observation, dual missions and formation flying.
- Increase competitiveness of the current European products (Hall Effect Thrusters, ion engines, FEEP, HEMPT, Helicon Radiofrequency thruster, etc.). In this process the qualification of the EP products is one of the main needs.
  - HET is now at TRL 9 and short term priority should be put on competitiveness
  - T5 is now at TRL 9 and short term priority should be put on competitiveness
  - T6 is in process of qualification on BepiColombo.
  - HEMPT is being qualified on first SmallGEO missions; a delta qualification for other platforms should follow [4], [5].
  - Since one common requirement for Hall Effects Thrusters and Gridded Ion Engines is the need for either a discharge cathode or a neutraliser cathode, provision of common interfaces could have tangible benefits for EP systems
- Use of the current flight data (Artemis, Deep Space 1, Dawn, Smart-1, GOCE, commercial telecommunication satellites, etc.) to validate the models that will be used by the spacecraft designers in the future. The EP community would benefit significantly from better use of existing flight data:
  - Fund activities for data analysis and model validation
  - Ensure data access to all participants involved in the program
- Standardization of engineering processes and testing facilities employed in the design, manufacturing and qualification of the current electric propulsion systems.
- Preparation for the ultimate goal: the full electric propulsion spacecraft where the benefits of the use of electric propulsion will be maximized by designing the spacecraft around the electric

propulsion system. Industry encourages ESA to propose preparatory actions to validate the concept of full electric spacecraft. Versatility is expected to support a wide range of missions.

- Increase EP autonomy: it should be of general interest to assess how at system and EP sub-system level the autonomy can be increased for EP use for long duration mission.
- In the commercial market the volume of EP systems produced will be high due to the very nature of the field. However, in the scientific arena there are fewer missions and they usually require a higher level of sophistication: synergies between these projects and the commercial sector should be reinforced.
- At least one Ion Engine, one HEMPT, one Hall Effect Thruster and one FEEP should be fully developed and commercialised in order to keep Europe at the forefront of the technology and enable new mission with very stringent requirements in controllability and propellant mass availability. Additional concepts such as mini-ion engines, (e.g. MidGITS, RIT-µX) mini-Hall effect thrusters (e.g. HT-100, HT400), Resistojets (Xenon), Arcjets, mN-FEEP, Colloids and PPTs should also be seriously considered in development programmes in order to enlarge the possibilities of the European industries in competition for new spacecraft (minisatellites limited in power and/or mass, LEO platforms, etc.).
- Extended research on non conventional propellants (e.g., Ar, N2, or gas mixtures containing Xe, O2, CO2, a.s.o.) should be considered
- Consider the use of MEMS components for electric propulsion in order to increase competitiveness by decreasing mass, volume and power of the different subsystems.
- A higher quality/cost ratio, performance/mass ratio, versatility and lifetime could be achieved with the European electric propulsion technologies if a proper funding is provided during the next 5 years
- A sufficient amount of dedicated test facilities and standardization of test procedures is needed in Europe to accomplish a successful development and qualification of the electric propulsion systems, including EMI.
  - Generally, care needs to be taken in adopting a "one size fits all" test approach
  - Each large facility in Europe is significantly different, and whilst there may be some perception that common procedures can be implemented, it is unlikely that facility diagnostics can be standardised in a cost-efficient way.
  - Development of a European certified calibration facility for diagnostics and probes.

ESA PROPULSION LAB (EPL)

Spacecraft propulsion systems are very important for space applications. Europe is developing several types of electric and chemical thrusters for application to many satellites, some of them with very stringent requirements such a micro-Newton controllability, long lifetimes and high power thrusters. Design, manufacturing and testing of such thrusters is a complex activity that requires a great effort. Full characterization, qualification, acceptance and plume interaction tests are mandatory in the full assessment of these technologies. Furthermore a clear assessment of the potential interactions between the thrusters and the spacecraft is mandatory for many projects. The ESA Propulsion Laboratory (EPL) at ESTEC has set up facilities that are currently used in the preparation of several missions such as Lisa-pathfinder, GAIA Cryosat, GOCE, Small GEO, etc.

ESA PROPULSION LAB (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:

- GOCE (cold gas and ion engines),
- 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 ESA 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 Radio Frecuency ion engine (RIT-10) lifetime test 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.

The ESA propulsion laboratory has extended its activities also to chemical propulsion systems such as cold gas thrusters. The work performed for example in cold gas microthrusters will help projects such as Gaia, Cryosat and Small GEO to find out the best technology for its use in future spacecraft.

Currently the EPL is building a flow bench that will allow tests of propulsion components.

The EPL changed physically its location at ESTEC in 2007. 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 were set up allowing to perform direct measurements of microNewton levels and helping to assess the real thrust noise at these low levels inside the EPL vacuum chambers. Furthermore, medium power electric propulsion thrusters will be tested in the future due to the availability of upgraded facilities.

EPL ORGANIZATION

The laboratory is managed by the EPL manager assisted by the EPL infrastructure and quality manager.

The EPL responsible is the person in charge of the normal operation of the lab.

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 is 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, EPL infrastructure manager and the head of the Propulsion and Aerothermodynamics Division) together with the normal customers who are consulted frecuently.

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 were obtained in 2004 by the EPL and have been renewed now until 2012. 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.

A specific annual steering board has been nominated comprising the EPL management and the main projects representatives. This board assesses the work performed within one year and design the strategy of EPL in investments and activities for the next year.

The EPL areas that required investment are:

- Vacuum facilities
- Diagnostic packages (Langmuir, Faraday probes, Retarding Potential Analysers, Quartz Cristal Microbalances, etc.)
- Data Acquisition systems and Power Supplies.
- Quality issues (procedures, instrument calibration, etc.)

EPL FACILITIES

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 (up to 10 exp-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 chemical activities such as flow benches.

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.

Features of Testing Facilities at EPL:

- 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

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 has seven vacuum facilities. Each facility is equipped with a vacuum tank including the pumping system and sensors, test racks including high- and low- voltage power supplies and Data Management Systems, computers for data acquisition and test control, and ancillary equipment for the test execution. The main room is rated cleanroom class 8 (equivalent to class 100,000) and four vacuum facilities are located on a 180 tonnes concrete bloc for seismic noise isolation. The EPL is also including an assembly room with laminar flow benches and optical microscope for visual inspection, a control room for remote testing and observation of the main room, a basement for pumps and compressors, and a storage room.

Specific diagnostic systems available at EPL include two Mettler-Toledo high-precision (0.1 milligram) electronic load-cells customized for miliNewton thrust measurement of cold gas thrusters, a NPL double-pendulum compensated stand for microNewton thrust measurements [1,2], two Alta specially-designed thrust balances for miliNewton thrust measurement of EP thrusters, two Hiden Analytical Mass Spectrometers, a Leybold Transpector Gas Analysis System, and various systems based on fixed or movable electrostatic probes for plume analysis.

The laboratory offers the following capabilities:

- Design, preparation, and execution of performance characterisation and endurance tests of electric thrusters in the range 1-40 milliNewtons.

- Performance tests of components for electric propulsion: cathode/neutralisers (1-10 Amps), propellant feeding systems (0.01-20 milligrams per second (Xe)), and power supply and conditioning units
- Design, manufacturing and validation of test diagnostic equipment (thrust stand, data acquisition systems, diagnostic probes)
- Certification of thrust, mass flow and electrical power measurements based on ISO 170125

The design and manufacturing of very specific diagnostics is normally realised in collaboration with external entities, nevertheless the EPL has independent capabilities to carry out this kind of activities. Figure 6 shows a Microthrust Thrust Balance developed by NPL for microthrust thrust level (1-100 microN).

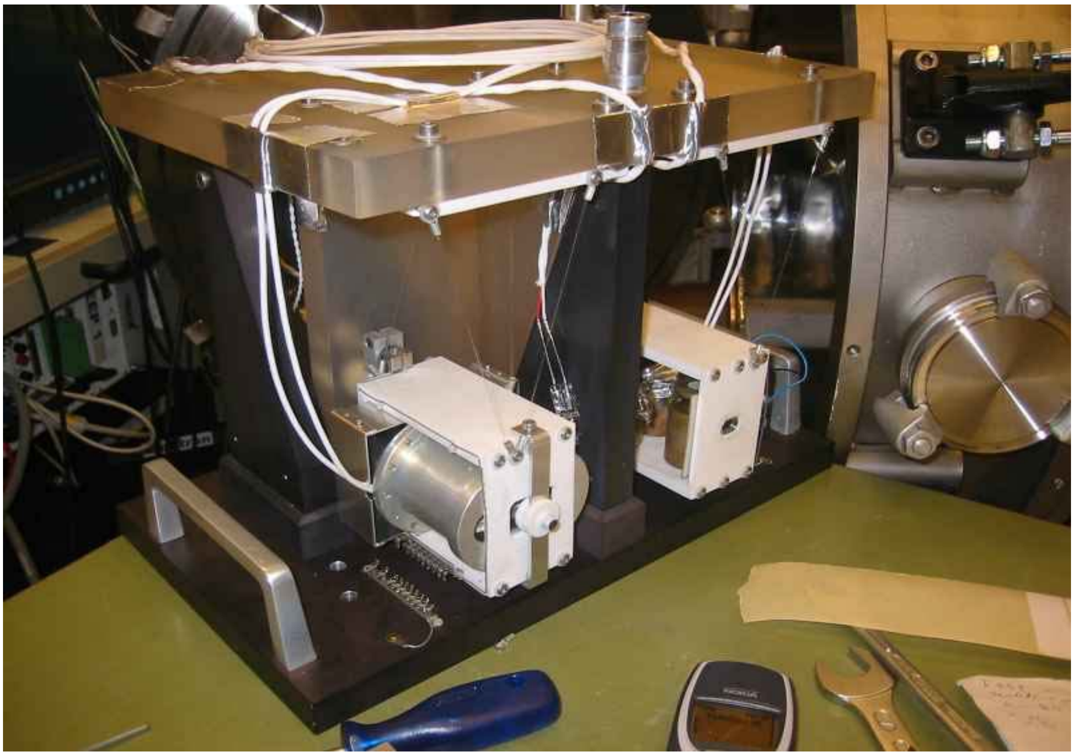

Figure 6: Micro Thrust Balance at EPL.

The new location of EPL at ESTEC has allowed to building a seismic block that will improve the high frecuency noise isolation to allow direct thrust measurements with specific microthrust balances. For the low frecuency noise isolation, active systems have been designed and will be tested within 2008. Figure 7 gives a panoramic view of EPL.

Figure 7: View of EPL.

CONCLUSIONS

After the successful flight of many electric propulsion thrusters, the current challenge is to reduce the non-recurring cost of the systems. In general the main points that the Electric Propulsion Community is going to face in the near future are:

- All the flight data that is available today should be carefully evaluated to extract lessons learned and inject them in the new programmes.
- Scaling up and down of the current EP designs and future concepts need to be pursued.
- To avoid ITAR restrictions, European companies should develop capabilities in components that today are mainly developed at USA (Moog, Vacco, etc.).
- New European facilities for EMI must be pursued to allow engine providers testing these engines in Europe.
- New telecommunication, Earth Observation and Science missions should be assessed from the point of view of the EP technology.
- Exploration may be the perfect arena to impulse the high power EP system (Hall Effect thruster, Ion Engine, MPD, etc.).
- ESA Propulsion Lab is an asset to the development and coordination of activities in Europe in the field of Electric Propulsion.

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