European Space Agency Activities in Electric Propulsion

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Abstract: The use of Electric Propulsion (EP) to perform orbit raising manoeuvres besides the station keeping operations in telecommunication satellites will allow primes to save hundreds of kilos of propellants allowing very low cost in launchers. Furthermore, new scientific and Earth observation missions dictate new challenging requirements for propulsion systems and components based on advanced technologies such as microNewton thrusters. New space missions in the frame of exploration will also require sophisticated propulsion systems to reach planets such as Mars or Venus and in some cases bring back to Earth samples from asteroids or comets. Finally the use of Electric Propulsion to perform orbit raising saving huge amounts of propellant has also attracted the attention of the future Galileo programme at ESA, the use of EP will allow to place 4 spacecraft in Ariane 5, 3 spacecraft in Soyuz and one in Vega, allowing low launcher costs. Due to all these new space projects, 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. 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 present the current and future challenges of the electric propulsion in Europe.

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Nomenclature

EP	=	Electic propulsion
FEEP	=	Field Emission Electric Propulsion
GTO	=	Greostationary Transfer Orbit
HET	=	Hall Effect Thruster
LEO	=	Low Earth Orbit
LISA	=	Laser Interferometer Space antenna

I. Introduction

The use of Electric Propulsion in the telecommunication space market is a key issue to improve the position of the European space sector . The high specific impulse provided by the electric propulsion technology will allow saving important amounts of propellant that will permit the use of smaller and cheaper launchers. The announcement of Boeing in 2012 on the procurement of 4 telecommunication spacecraft (platform 702SP) for Satellites Mexicanos (Satmex) and Asian Broadband Satellites (ABS) for 125 million dollars each including launch, thanks to the use of electric propulsion for orbit raising from GTO to GEO, has been noted by European operators and primes. ESA is now involved in the preparation of several telecommunication programmes (Neosat, Electra, Hercules) that will use electric propulsion not only for North South Station Keeping operations but also for orbit raising manoeuvres, paving the road for the commercial use of Astrium and Thales platforms with electric propulsion on board.

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Boeing has selected the Falcon 9 launcher for the launch of these spacecraft. The new technology may also be welcome by Europe's Arinespace consortium, whose heavy lift Ariane 5 typically needs to match two spacecraft, one large and one medium, for commercial launchers. Adding the option of a low weight 702 SP, Arianespace could accommodate larger primary payloads co-manifested with a single all electric spacecraft without exceeding the rocket's total capacity of more than 9000 kg to orbit.

The Navigation directorate is also assessing the possibility of the use of electric propulsion to perform orbit raising manoeuvres for the next generation of the Galileo programme. Electric Propulsion, used to transfer within 12 months each satellite from the injection orbit (LEO or GTO) to the target orbit (MEO or IGSO), would allow to: increase the Galileo payload capability; make the Galileo platform compatible with any launcher of the Arianespace launcher family; reduce the launch costs by increasing the number of satellites per launch (4 satellites in Ariane 5 shared launch into standard GTO, 3 satellites in Soyuz ST dedicated launch, 1 satellite in Vega dedicated launch),

Science missions such as the current Bepi Colombo and future missions such as Marco Polo will make use of electric propulsion technologies based in the successful experience of other scientific missions such as Smart-1. Earth observation missions such as GOCE are already flying electric propulsion and future gravity missions will also make use of electric propulsion technologies [1].

Exploration future missions could also benefit of the use of this high specific impulse technology as it has been stated in the assessment ESA studies on this subject (R2D3).

De-orbiting of satellites and operation of small satellites in low orbit for migration control and observation missions are some of the future missions interested also in the use of electric propulsion.

Another electric propulsion system with a high potential is based on FEEP thrusters that is a potential candidate for scientific ESA missions such as LISA. These thrusters will have to provide micro-Newton thrust levels with an accuracy of less than one microNewton and very low noise level. ESA is developing this technology.

Low power class Hall Effect thrusters (mini-HET) are currently available at breadboard level. Qualification of such thrusters aims at application on small-medium-size platforms and spacecraft (limited in power) to fulfil the manoeuvre requirements for drag compensation, station keeping, and disposal at End Of Life (EOL).

Miniaturised versions of Ion Engines (mini-Ion Engine) are currently available at engineering level. Qualification of such thruster will enable drag free and formation flying condition.

Pulsed Plasma Thruster (PPT) Resistojets and Arcjets are also being considered due to their robustness and simplicity.

European industries and research centers are active in setting up a network of EP testing facilities (ALTA, SNECMA, QinetiQ, AEROSPAZIO, Giessen University, TAS I-Florence, Thales, ONERA, IRS Stuttgart, etc.) which will allow cross-verification of test results (even between European and non-European thrusters). The possibility of cross-verification of European and non-European thrusters in different facilities could increase the acceptability of electric propulsion systems on new missions. EP testing facilities are requested for long duration tests and acceptance testing. In addition the space community recognizes the need of having test facilities ready to be used as back-up when the planned one cannot be used. Furthermore, it is mandatory that the tests performed in different test facilities on the same thruster provide congruent results. This comparability of results is of extremely importance for the developers of micro-Newton thrusters (FEEPs, colloid, mini-ion engines) due to the need of such developers to clearly demonstrate that their engines are capable of controlling the thrust at such low regimes. The ESA Propulsion Lab (EPL) at ESA is having an important role in this effort.

New activities on EP systems/spacecraft thruster interaction are being initiated and an effort to standardise the development activities and test procedures is in place with the leadership of ESA.

II. Application of EP to Space Missions

A. TELECOMMUNICATION MISSIONS

The announcement in 2012 of the contract signed between Boeing and Satellites Mexicanos (SatMex) and Asian Broadcast Satellites (ABS) for the procurement of 4 spacecraft that will use electric propulsion to perform orbit raising manoeuvres from GTO to GEO allowing saving around 1300 kg of hydrazine and thus reducing the mass of the spacecraft to less than 2500 kg, has shaken the telecommunication market. These savings will allow Boeing to reduce the cost of the spacecraft (100 million dollars) and also to reduce drastically the launch cost by using Falcon 9 (25 million per spacecraft). The use of electric propulsion for orbit raising will allow operators to save more than 30% of the cost. The implementation of this operation (thrusting time, power, thermal control, AOCS, etc.) is now one of the most important activities of the space sector.

The Telecommunication market requires now a qualified product, life test demonstrated, EMC characterized, and in orbit demonstrated. EP systems with Hall Effect Thrusters and ion engines have demonstrated good performance in orbit. The main challenge is now competitiveness. American engines from Aerojet and L3 are competing with the European engines (SNECMA, QinetiQ, Astrium and Thales). Today ESA is carrying out several activities to allow European companies to gain competitiveness in the world market.

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 NEOSAT will offer a very high power payload capability (up to 16 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 Alphasat satellite (6.5 tons and 12 kW) was launched on July 2013 with the SNECMA thrusters (PPS1350) on board to perform NSSK operations (see Fig.1).

Small GEO 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 [4] [5]. EDRS (European Data Relay Satellite) may also have HEMPT to perform NSSK operations [4]. Furthermore the new OHB platform ELECTRA will make use of electric propulsion to perform NSSK manoeuvres together with orbit raising, the spacecraft will weight less than 2500 kg and will have a power of around 8 kW.

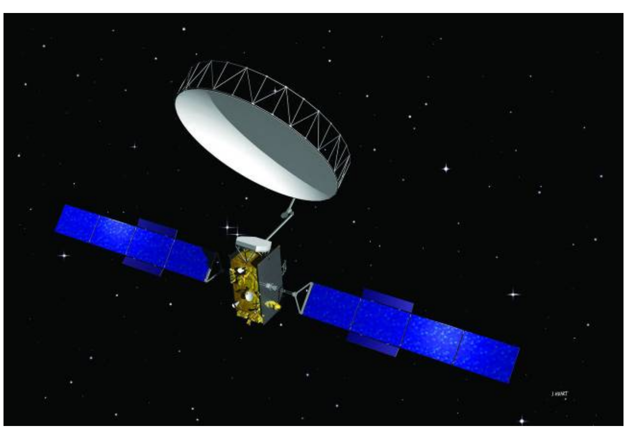

Figure 1. Alphasat concept

B. NAVIGATION

The Galileo 2G programme is targeting the possibility to increase the Galileo Payload capability without impacting the launch costs (and possibly reducing them). The need to increase the size of the Galileo Payload (mass and power) is deriving from system needs, which are considered to become essential in a new scenario of Galileo, starting in 2020 and having its final configuration not earlier than 2030.

Today, there are no margins in the Galileo platform to allow an increase in the payload capability, due to mass and power limitations established by the adopted launch strategy (Soyuz, dual launch, direct injection). Therefore, any increase in payload would lead to a single Soyuz launch, with a negative impact on costs.

In 2011-2012 a number of studies have been performed internally to ESA to assess the challenge to increase the Galileo payload capability without impacting the launch costs. These studies have been conducted in the ESA Concurrent Design Facility (CDF) under the acronym of AGILE, Advanced Galileo Injection in Low earth-orbit using Electric-propulsion, and constitute the phase O of the Galileo 2G programme.

The AGILE studies concluded that the increase in payload capability could be achieved only by using Electric Propulsion to transfer the satellite to operational orbit and by changing the launch injection policy.

Electric Propulsion, used to transfer within 12 months each satellite from the injection orbit (LEO or GTO) to the target orbit (MEO or IGSO), would allow to:

- increase the Galileo payload capability;
- make the Galileo platform compatible with any launcher of the Arianespace's launcher family;
- reduce the launch costs by increasing the number of satellites per launch, with the goal to launch:
  - o $\geq$ 4 satellites in Ariane 5 shared launch into standard GTO, leaving a co-passenger mass $\geq$ 3000 kg
  - o $\geq$ 3 satellites in Soyuz ST dedicated launch
  - o $\geq$ 1 satellites in Vega dedicated launch.

The AGILE studies have considered the use of several Electric Propulsion SubSystems (EPSS) from different European suppliers. In particular three Electric Propulsion technologies were assessed: Gridded Ion Engines, Hall Effect Thrusters, HEMPT. ESA is currently funding the European sector to adapt these engines to Galileo evolution.

C. SCIENTIFIC MISSIONS

1. Interplannetary exploration missions: Smart-1 and Bepi Colombo

Electric thrusters as the primary propulsion system for these missions will 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.

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 fig.2).

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.

Marco Polo is a potential ESA mission to the Asteroids, to collect and bring to Earth, material found at the Asteroid surface. ESA has a preliminary mission study with both Astrium and Thales which have baselined a subsystem based on the Snecma (F) PPS1350G thruster for the transfer to and from the selected asteroid. The Preliminary Requirements Review will take place in October/November to support the M3 Cosmic-Vision mission down-selection in February 2014 by the Science Programme Committee as well as the potential preparation of Phase B1.

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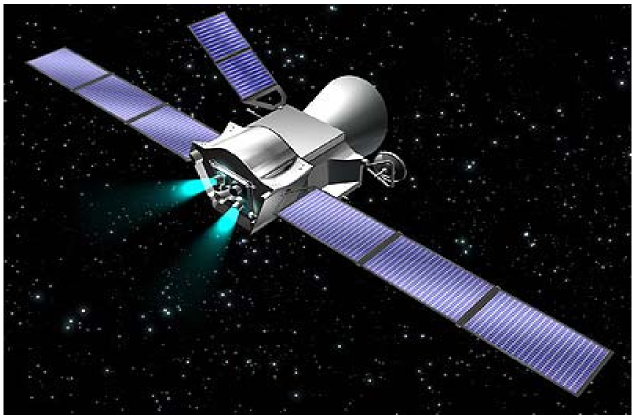

Figure 2. The Bepi Colombo Mission Concept

2. High precision scientific missions: Lisa-pathfinder, LISA, Darwin, 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 (Fig.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.

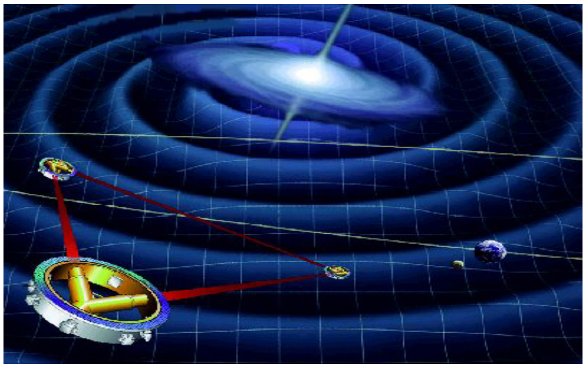

Figure 3. The LISA Mission Concept

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 micro newton 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 micro 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. Mini-ion engines could also fulfil these requirements.

LISA will rely on technologies that have never been tested in space, including the microthrusters system, so neither of them could be built without a previous space demonstration. This is the objective of the Lisa-pathfinder (see Fig.4) 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 cold gas thrusters. The micro colod gas thruster is designed to operate during the drag-free mode and the cold gas for all the other AOCS functions. 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. Mini-ion engine thrusters and Field emission thrusters could also provide the propulsion requirements for LISA but they will not fly in lisa-pathfinder due to the tied schedule of the mission.

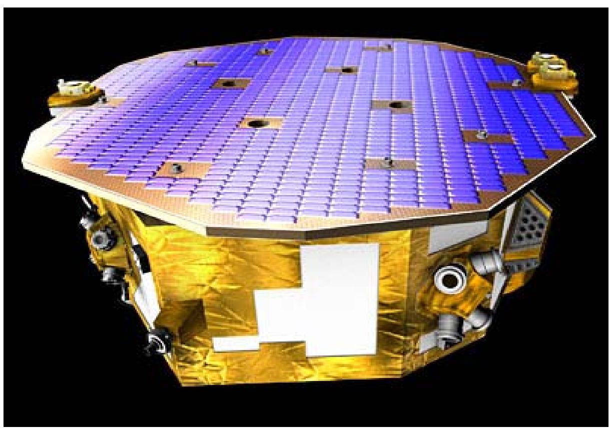

Fig.4 LISA-Pathfinder Concept

D. 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.
ESA is currently studying the future evolution of the Exploration programme. It is clear that it will be very expensive to engage in a complex mission to Mars directly, especially in the frame of the current economic crisis. Instead of thinking on unrealistic missions due to their high cost, ESA is reflecting on proposing a technology mission that allows to test all the future technologies required for exploration missions. Any mission to Mars or any planet in the frame of exploration will require lifting weight to LEO, then assemble different structures and send this spacecraft to interplanetary trajectory, at that point the spacecraft will need to orbit the planet, descend, collect samples or bring astronauts and ascend again before coming back to Earth. High Power Electric propulsion (>10kW) could be a perfect candidate for performing interplanetary cruise and will need to be considered during this technology mission that could pave the way to future and more ambitious missions.

E. 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 has performed 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 Fig5.) is a low-Earth orbiting spacecraft (275 km) that has a small cross section of approximately 1 m^2, 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 effects 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].

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.

The success of the ion engine in the GOCE spacecraft has demonstrated the potential of this technology for fine control of satellites flying in LEO.

The GOCE satellite will end his operational life at the end of 2013.

A new post GOCE mission is being designed at ESA, Next Generation Gravity Mission for Monitoring the Variations of earth's gravity (NGGM). This mission is composed of two small satellites flying in formation in a very low orbit and is considering the mini-ion engine (Astrium) to compensate very small drag force (see Figure 5). Milli-Newton In thrusters (FOTEC) are also candidates for this mission.

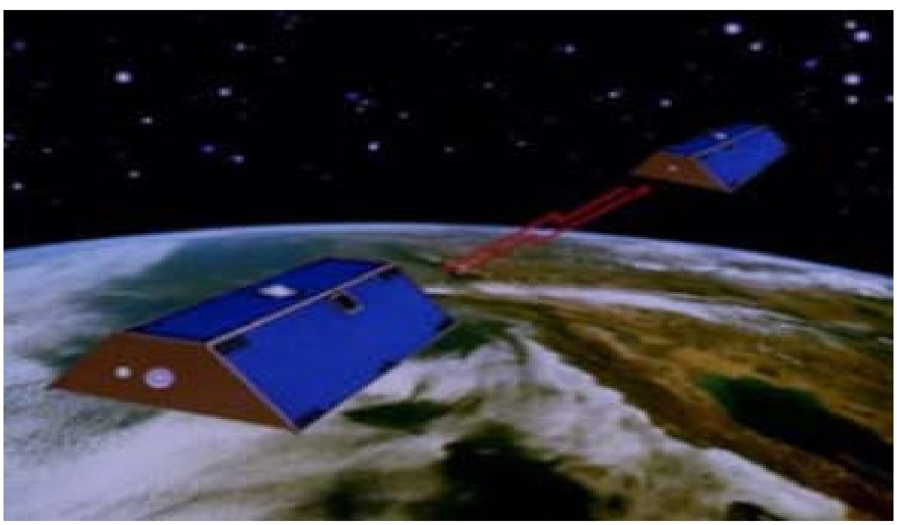

Fig.5. The NGGM mission

III. European Strategic Interest

A. Telecom Market

As main customer, telecom market is the driver / pathfinder to develop robust / efficient / competitive EP systems. NSSK and orbit topping maneuvers requirements can be fulfilled by EP thrusters. The availability of high total impulse Hall Effect thrusters, ion engines and HEMPT will allow Europe to compete worldwide in the telecommunication market. Competitiveness improvement of European EP systems is the main challenge for this market. Development of high power EP systems such as the Snecma PPS 5000 and the QinetiQ T6 may enlarge application of EP behind NSSK.

B. Navigation

The use of electric propulsion to rise the orbit from LEO or GTO to HSO or IGSO in Galileo will allow huge savings of propellant that will have an impact in the amount of spacecraft that can be placed in a particular launcher.

C. Scientific Mission

Microthrust propulsion systems will enable scientific missions requiring very fine control and will allow Europe to deploy state-of-the-art scientific spacecraft. High power ion engines and Hall Effect thrusters will allow efficient interplanetary cruise.

D. Exploration

High Power Electric Propulsion Systems are one of the technologies that need to be developed to enlarge the frontiers of space exploration. Therefore specific exploration requirements should be defined. Enlarging the frontiers of space exploration suggests planetary applications. This may require larger thrusters, new propellants, higher onboard power systems and different materials, all of which shall be investigated.

E. Earth Observation

Based on the successful operation on GOCE, assess the use of Electric Propulsion systems for future missions is taking place at ESA. The post-GOCE mission has baselined mini-ion engines for this mission.

The main challenges for Electric Propulsion (EP) system for near future are [6] [7]:

- Improving the access price to overall EP system, starting with Hall Effects Thrusters, Ion Engines and HEMPT.
- Qualification of HEMPT, diversification of this technology to other thrust and specific impulse ranges, exploration of clustering capabilities
- Qualification of microthrusters (mini-ion engine, mini-Hall effect thrusters, field emission thrusters) 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.
- 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.
- 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.

- Ion Engines, HEMPT, Hall Effect Thruster and FEEP should be fully developed and commercialised in order to keep Europe at the forefront of the technology and enable new missions with very stringent requirements in controllability and propellant mass availability. Additional concepts such as mini-ion engines, mini-Hall effect thrusters, 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.). MPD and Helicon-Antenna thruster should be developed for a long term Exploration scenario.
- Extended research on non conventional propellants (e.g., Ar, N2, or gas mixtures containing Xe, O2, CO2, a.s.o.) and new materials for extending life capabilities of EP engines 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 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.
    - the development of a European certified calibration facility for diagnostics and probes could be the answer.

IV. Conclusion

European electric propulsion systems are being qualified or under development for power levels up to 5 kW. These technologies are bringing Europe in the position not to depend and even to be competitive with other Countries for the use of these technologies on current and future missions in the commercial and institutional areas.

Further to the above, it is concluded that:

1. Four Electric Propulsion (EP) technologies are today being developed in the 5 kW range: PPS-5000 at SNECMA (F), T6 at QINEIQ (UK), RIT-22 at Astrium and HEMPT at Thales (D). The first two technologies are better positioned from the TRL level point of view. The RIT-22 does not have a power conditioning unit and the HEMPT development at high power was stopped some years ago. These technologies will provide high thrust and high specific impulse capabilities.
2. High power EP short term applications: telecommunication (orbit maintenance of 16 kW platforms) and science (interplanetary missions such as Bepi Colombo) will be able to make an immediate use of these technologies.
3. High power EP long term applications: high power telecommunication spacecraft (orbit-raising and orbit maintenance of 20 kW platforms), science (interplanetary missions) and exploration (the Moon, Asteroids and Mars) will require such systems.
4. Small platforms such as Small GEO and Electra are going to play an important role thanks to the use of launchers such as Falcon 9 that will allow to launch high power payloads in small platforms thanks to the use of electric propulsion for orbit transfer.
5. In order to improve European competitiveness some strategies could be envisaged in this domain: re-usability of systems such as T6 baselined in BepiColombo or PPS-5000 or RIT 22 in new missions and new developments such as high power HEMPT to enable new missions.
6. Europe can and shall benefit from the current advanced status of these technologies to enable non-dependence in this field and even to propose the provision of electric propulsion systems as part of possible collaboration on future international collaborative programmes in Science and Exploration.
7. ESA is also developing microthrusters such as mini-ion engines, FEEPs, mini-Halls, etc. with capability to fulfil stringent Science and Earth Observation requirements. ALTA, FOTEC, etc. are busy with these developments.
8. The next Galileo programme is planning the use of electric propulsion to perform orbit raising from LEO or GTO to High Elliptical Orbit. European EP providers are well positioned for this application.

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