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Abstract: ESA is supporting the European Industry in the field of space telecommunications by having more performing satellites capable of saving more than one thousand kilos of propellant by using electric propulsion for orbit raising manoeuvres. ESA Neosat and Electra satellites will perform orbit raising and station keeping manoeuvres with Electric Propulsion systems which will allow to reduce the launching costs by selecting smaller launchers or participating as a co-passenger with another spacecraft in the same launcher. New constellation of hundreds of spacecraft are being developed and they will make use of electric propulsion in the next years. Besides, 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 and 3 spacecraft in Soyuz, 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 AlphaBus, GOCE, Smart-1 and Artemis have paved the way for the use of electric propulsion in future ESA missions: Bepi Colombo, Small GEO, LISA, etc. Furthermore, ESA is the coordinator of an activity with the European Community (EPIC) that will provide a clear roadmap for preparing the future of the Electric propulsion in Europe. This paper will present the current and future challenges of the electric propulsion in Europe.

Nomenclature

EP = Electric Propulsion
FEEP = Field Emission Electric Propulsion
HET = Hall Effect Thruster
HEMPT = Highly Efficiency Multistage Plasma Thruster
NSSK = North South Station Keeping
GEO = Geostationary Earth Orbit
EOL = End Of Life

I. Introduction

Geostationary telecommunication satellites are one of the main envisaged commercial applications of electric propulsion systems. The use of EP systems for station-keeping and, more recently, orbit raising, allows for a very significant reduction of propellant mass. This reduction can be translated into larger payload mass, or in a reduced total mass, which can in turn reduce significantly launch costs. Both of these cases imply economic benefits for the

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operators, which means a competitive advantage for the satellite manufacturers that can offer EP systems in their spacecraft buses. In addition, the availability of high power in telecommunication satellites also allows for the operation of EP systems without requiring major changes in the platform. On the other hand, the low thrust levels provided by EP systems mean extended firing times to obtain the required deltaV, which imply longer trajectories to reach the final orbit in GEO. This implies reduced revenue for telecom satellite operators in the short-term, so there is a trade-off between the income lost and the savings in the medium to long-term obtained due to the use of EP, which is considered very much positive in the long run. Constellation of satellites for internet services (OneWeb, LEOSAT, Space X, etc.) are being currently developed employing electric propulsion for orbit maintenance and de-orbiting manoeuvres.

The Galileo 2G programme is targeting the possibility to increase the Galileo Payload capability without impacting the launch costs (and possibly reducing them) by the use of electric propulsion during the orbit raising manoeuvres of the different spacecraft.

Space science plays a prominent role within Europe's space programme, and has been at the core of ESA's activities since the early 1960s. Activities in space science effectively underpin ESA, building European industrial technical capacity, and bringing together European national space programmes.

The Horizon 2000 long-term plan for space science formulated 20 years ago, is now almost completed, and its successor, Horizon 2000+, is coming to fruition with a wealth of scientific satellites and space telescopes in orbit and producing important scientific results. The main next step is the ESA's 'Cosmic Vision' programme, which aims to build on the past successes and answer some of the outstanding questions about the Sun, our Solar System and the Universe.

A number of the planned and proposed missions require the application of significant deltaV to achieve the scientific goals. These missions will be enabled by the application of high power solar EP, which can offer significant benefits in terms of both mass and transfer duration, compared to traditional chemical propulsion solutions.

In the near-term, the BepiColombo mission is now in the implementation phase, and has selected a solar EP system based on the QinetiQ T6 GIE to perform the transfer to Mercury.

In earth Observation, missions such as NGGM (New Generation Gravity Missions) will use electric propulsion thrusters (mini-ion engines and or field emission engines) to maintain the flying formation of a fleet of satellites.

The European Commission has recognises the importance of Electric Propulsion for space missions and has funded a specific project, Electric Propulsion Innovation & Competitiveness (EPIC), that aims to provide a clear integrated roadmap of activities and a master plan for its coordination and implementation through a Strategic Research Cluster (SRC) on "In-space Electrical Propulsion and Station-Keeping". The produced roadmap when implemented through the operational grants of the SRC and when correctly coordinated by the EPIC Programme Support Activity (PSA), will contribute to increase the Technology Readiness Level (TRL) of future EP technologies. This will allow the demonstration/validation of developed EP thrusters and corresponding systems during a validation flight to be executed around 2024.

EPIC also intends to provide advice to the European Commission (EC) on the calls for the SRC operational grants and to contribute to the assessment of the evolution and results of those operational grants with respect to the overall SRC roadmap. ESA is coordinating the ESA project with the European Space Agencies (CNES, CDTI, UKSA, ASI, BESPO, DLR) and industry Associations (Eurospace and SME4Space).

II. Space Missions using Electric Propulsion

A. Telecommunication:

The largest single market for electric propulsion is in commercial telecommunications satellites. This market is dominated in the west by a small number of US and European suppliers, namely Boeing, Space Systems Loral (SSL), Airbus Space and Defense and Thales Alenia Space, who are all offering large platforms (6.5 tons class). SSL, Airbus Space and Defense and TAS were offering a conventional approach with launch into GTO and a chemical propulsion transfer from GTO to GEO transfer during the last years and either chemical propulsion or electric propulsion systems for station keeping, nowadays both primes are offering platforms using full electric propulsion transfer and orbit maintenance capabilities. Boeing offers since 2012 an alternative approach with launch into Sun Synchronous Transfer Orbit (SSTO) with a combination of electric propulsion and chemical propulsion transfer to GEO, utilising the more efficient inclination change maneuvers possible at the high apogee of the SSTO. All station keeping is then performed with electric propulsion.

The market has evolved in recent years, and it is continuing to evolve, based on a range of developments in launch services, platform technologies and operator requirements.

Launch services for the large commercial platforms are dominated by Proton and Ariane-5. These launchers have high prices for heavy payloads despite aggressive pricing strategy by Proton since 2013. Smaller platforms (< 3.5 tons) may be launched as dual payloads on Proton and Ariane-5 or as single payloads on Falcon 9. The possibly to launch dual payloads on Falcon 9 has emerged with Boeings announcement of its small 702SP platforms (2 tons class). The development of re-ignitable upper-stages has introduced flexibility in to the launcher market and allows a range of sub- and super-synchronous transfer orbits to be offered, reducing the overall velocity increment requirement on the spacecraft bus, and enabling electric propulsion to be considered for orbit topping / raising as well as station keeping.

Recent developments in platform technologies have been aimed at increasing the available payload fraction and accommodating larger, more powerful payloads. These developments have focused on the power subsystems and thermal control systems necessary to accommodate higher payload power. This has the advantage that more power can be made available for electric propulsion, especially during orbit transfer phase when the payload is not operational.

With respect to operator requirements, there is a sustained request for lower cost-per-transponder, coupled with a demand for larger transponder capacity and longer operational lifetimes. Despite the need of a higher capital investment many existing operators continue to be attracted by larger, higher-power spacecraft. However, in emerging markets where capital investment may be limited, smaller spacecraft may be more appealing. The telecommunications market is expected to continue to be dominated by the large spacecraft class, but with increasing interest in smaller platforms for expansion into emerging markets.

Boeing's announcement in 2012 of sales of four of its new all electric small platform (702SP) has produced significant interest in the commercial telecommunications market. Their aggressive approach to reduce satellite mass and allow dual satellite launches on the Falcon 9 launcher could lead to very significant reduction in operator costs. Although many of the satellite suppliers appear to be skeptical about the Boeing approach, they are all now reviewing their offerings with a view to increase competitiveness by increasing their use of electric propulsion. The first Boeing spacecraft were launched on the 1 March on board a Falcon 9 launcher.

It is clear that the trend to increased use of electric propulsion will continue in the telecommunications market and that higher power thrusters will be needed to meet both the orbit raising and station keeping needs of future small and large platforms.

- Existing platforms and short-term developments

For telecommunication platforms a largely independent market exists in the United States, over the past decade commercial (and institutional) missions have taken the lead in exploiting the potential offered by electric propulsion. Both Space Systems Loral and Boeing represent a significant threat to European commercial platform products and have each developed platforms using electric propulsion.

Boeing is the market leader, having already developed two generations of platform using electric propulsion. Their 601HP platform was the first western commercial telecommunications bus to fly electric propulsion in the form of the XIPS-10 gridded ion engine. Their current generation bus 702HP uses its high-power capacity (up to 18kW) to take full advantage of electric propulsion technology. The satellite is equipped with four 4.5kW XIPS-25 gridded ion thrusters that feature high power orbit raising and low power station keeping modes. Once on station, the ion thrusters are used to perform all station keeping and spacecraft momentum control functions.

Space Systems Loral (SS/L), through an agreement with Fakel (RU), have incorporated the SPT-100 Hall Effect Thruster into their LS-1300 platform. The four SPT-100 thrusters provide impulse for on-orbit inclination and eccentricity control as well as momentum control functions.

SES and Eutelsat have bought two spacecraft each to Boeing (~8kW, 2500kgr.) and Airbus Defense (~16kW, 4000 kg) and Space using electric propulsion for orbit raising and station keeping, therefore four spacecraft equipped with full Electric Propulsion systems will be launched in the next few years.

European industry has been relatively conservative in their adoption of electric propulsion technology compared to the US suppliers. Since 2002 European Primes have launched eight telecommunications satellites that use electric propulsion for station keeping. These platforms have retained a full chemical propulsion capability, such that electric propulsion was offered as an option to the existing all chemical product range, rather than as a separate product line. To date Inmarsat-4 and Intelsat-10 spacecraft have accrued more than 7,000 hrs of cumulated electric propulsion operations, increasing the confidence in the technology.

The European Large Platform Development AlphaBus, an ESA–CNES funded project for future high-capacity geostationary telecommunication satellites, was developed jointly by Airbus Space and Defense and Thales Alenia Space to enhance European competitiveness in the large telecommunication platform market. For the short-to-medium term needs, the AlphaBus nominal range is defined with a payload power between 12 and 18 kW and a payload mass between 950 and 1300 kg. The use of electric propulsion for North-South Station Keeping (NSSK) is a standard feature of the AlphaBus product, using the Snecma PPS-1350G Hall Effect Thruster. The spacecraft is operating today with good performances.

Although orbit topping is feasible with the PPS-1350G it would provide only a very small fraction (50 to110 m/s) of the needed transfer velocity increment (1.5 km/s). This option may be attractive on the smallest of the AlphaBus range when the spacecraft mass budget is marginal for one of the smaller launcher. For the nominal AlphaBus range work has started on incorporating an Electric Orbit Raising (EOR) capability to improve competitiveness and capability. These improvements are based on the extension of the PPS-1350E Hall Effect Thruster performance to enable orbit raising at a higher power operating point.

Both Airbus Space and Defence and Thales Alenia Space have recently embarked on upgrade programmes to extend the capabilities of their existing Eurostar and SpaceBus platforms.

Thales Alenia Space and Airbus Space and Defense have opted to reinstall electric propulsion (1350 W engines) on their platforms. The final evolution plans to introduce high power thrusters (5kW Class Hall Effect Thruster) to perform orbit topping and Station Keeping Functions using an advanced thruster pointing mechanism to perform the reconfiguration.

OHB’s Small GEO platform[5] has been designed from the start to use Electric Propulsion. With eight fixed thrusters mounted in pairs on the East-West-North-South edges of the spacecraft, North-South and East-West station keeping and momentum control functions can be performed simultaneously. Auxiliary propulsion (Xenon cold gas) is available to provide emergency attitude control functions. 2x4 electrical thrusters mounted on the E/W/N/S edges

- Medium to Long-Term Applications

In the US it is expected that Boeing will continue to market its large 702HP platform, using the XIPS-25 gridded ion engine system for the orbit topping and station keeping functions, toward operators seeking to replace or expand their existing fleets. In addition, following the announcement in 2012 of the first orders for their small 702SP ‘All Electric’ platform, it is expected that Boeing will target this platform at emerging markets, where the potential of low cost dual launch on Falcon 9 could significantly reduce capital investment cost for new markets.

The Boeing 702SP is a 2 ton/ 7.5 kW class platform which will use a common electric propulsion system, possibly based on the XIPS-25 gridded ion engine, for full orbit raising and all station keeping and momentum management functions.

Space Systems Loral, are known to be engaged in qualifying the Fakel (RU) 5kW SPT-140 Hall Effect Thruster. Once mated to a wide range deployment and positioning mechanism, developed by Loral, this will potentially offer a complete orbit raising and on orbit control capability using electric propulsion.

Faced with such competition it is reasonable to expect that the "market" will over time demand that European platform providers match the worldwide competition, by offering orbit topping on its large platforms and developing small platforms with 'all-electric' orbit raising and station keeping functions. All of the existing European platforms use the Fakel (RU) SPT-100 Hall Effect Thruster or the Snecma PPS-1350G Hall Effect Thruster. Since the total impulse capacity of the both of these thrusters is limited, existing configurations cannot offer significant orbit topping in addition to the baseline station keeping functions.

For the AlphaBus extended range, the situation is even more difficult. This platform range is targeted at for a maximum launch mass of 8.8 tonnes (maximum Ariane-5 ECA capability to LEO) and power extension to 22 kW. In this situation the total impulse capability of existing 1.5 kW thrusters (PPS1350/SPT-100) is marginal to perform the station keeping role. In order to maximize the payload mass fraction in this scenario, even relatively modest top-up durations will exceed the thruster capability. Whilst there is a potential to employ dedicated orbit raising thrusters, this de-optimises the propulsion system, thus requiring the availability of thrusters with a higher total impulse capability.

OHB Systems are working in partnership with SES-Astra and the ESA to develop a small 'all-electric' platform, named Electra (ARTES 33). The intension is to produce a small platform in the 2 – 3 tonne class which can compete with the Boeing 702SP by offering low cost launch options. The baseline design considers a four thruster configuration (2 + 2) with each pair of thrusters mounted on a boom mechanism to allow repositioning between orbit raising and station keeping functions. The requirement for orbit transfer duration to be less than 200 days necessitates the use of 4.5 kW class thrusters for orbit raising.

High-power electric propulsion is therefore needed to cover this range of large Telecom applications within the AlphaBus frame. High-power electric propulsion is also needed to compete in the worldwide Telecom market and provide a substantial orbit-topping capability for the whole platform range. The AlphaBus extended-range platform will be designed to provide up to 90-days orbit-topping (with a maximum 200 m/s velocity increment), requesting an additional 1 MNs for the thruster total impulse capability.

In the longer term high power thrusters will be needed to extend the total impulse capability of the electric propulsion systems and to increase the thrust available for orbit raising, so that larger fractions of the orbit raising function can be performed using electric propulsion while maintain an acceptable orbit transfer duration.

High-power electric propulsion is needed to save a larger fraction of the chemical propellant within the specified transfer duration and to extend the total impulse capability to be able to perform both orbit-topping and station-keeping with the same thrusters. With the increased thrust capability of the high-power thruster, wet mass savings are much more significant and the limitation of the maximum platform dry-mass is removed. In addition, novel thruster orientation mechanisms enable the operation of 2 thrusters in parallel with small thrust vector losses, rendering orbit transfer even more attractive.

The European reaction to the changing launcher market and commercial platform developments in the united states is now underway. Both NeoSat (ARTES-14) and Electra (ARTES-33) are intended to cover the small to medium class platform applications. Significant topping of between 4-8 months, or complete electric orbit raising configurations are expected from these developments. Thales and Airbus are now also offering full electric propulsion platforms capable to compete at world level.

In parallel both Airbus Space and Defence and Thales Alenia Space are working on extended versions of their existing developments, these being based on the availability of 5kW Hall Effect Thrusters and fully deployable thruster gimbals.

The new constellations of Space X with 4000 spacecraft or Oneweb with 700 spacecraft using electric propulsion for orbit maintenance and de-orbit manoeuvres with prices of 500 000 euros per spacecraft are bringing new challenges to the spacecraft designers and electric propulsion developers. These satellites will be placed in orbits around 1200 km and they have been designed to obtained the cheapest terminals on ground which imposes important challenges in the space architecture.

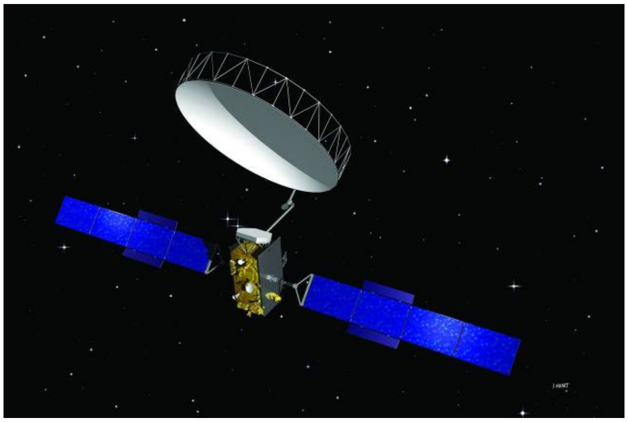

Figure 1: AlphaBus.

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:
    - ≥ 4 satellites in Ariane 5 shared launch into standard GTO, leaving a co-passenger mass ≥ 3000 kg
    - ≥ 3 satellites in Soyuz ST dedicated launch
    - ≥ 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[4]. ESA is currently funding the European sector to adapt these engines to Galileo evolution.

C. Science, Exploration and Earth Observation

Space science plays a prominent role within Europe's space programme, and has been at the core of ESA's activities since the early 1960s. Activities in space science effectively underpin ESA, building European industrial technical capacity, and bringing together European national space programmes.

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A number of the planned and proposed missions require the application of significant deltaV to achieve the scientific goals. These missions will be enabled by the application of high power solar EP, which can offer significant benefits in terms of both mass and transfer duration, compared to traditional chemical propulsion solutions.

In the near-term, the BepiColombo[1] mission is now in the implementation phase, and has selected a solar EP system based on the QinetiQ T6 GIE to perform the transfer to Mercury. A dedicated propulsion module is developed to transfer the two orbiter spacecraft to Mercury. It is anticipated that the BepiColombo propulsion module will be suitable for the transfer propulsion needs of future science missions. Re-use of technology in this way will offer the science programme considerably reductions in costs and development risk. The propulsion module will be used to transfer in around 6.5 years two scientific orbiters, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO), which will be dedicated to the detailed study of the planet and of its magnetosphere. Launch is planned in 2017.

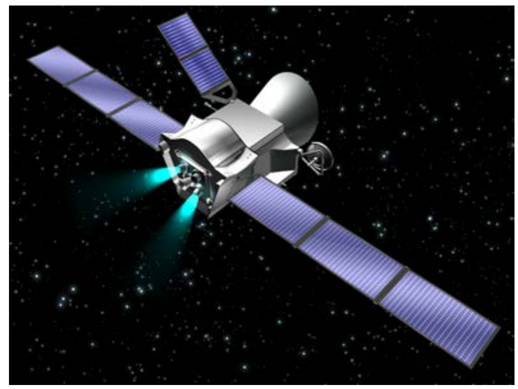

Figure 2: Bepi-Colombo spacecraft

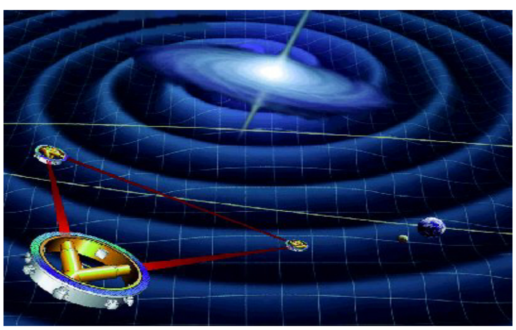

Figure 3: Principle of the LISA mission

One of the L-class mission proposed for ESA's Cosmic Vision 2015-2025 programme is the Laser Interferometer Space Antenna (LISA)[2]which aims 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 kilometres apart, will be constantly monitored with a high accuracy using laser-based techniques. A gravitational wave passing through the spacecraft will cause these bodies to vibrate, changing the separations between them. But the changes will be so subtle that in order to perceive them the position of each satellite must be controlled up to the nanometre level. 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 cold gas or electric propulsion thrusters (FEEP or mini-ion engines). The control torques and forces for the attitude and drag-free control during the operational phase could be given by the micro electric propulsion thrusters by providing a controlled thrust in the range of 1 to 100 µN, with a noise below 0.1 µN. LISA has been envisaged as an ESA/NASA collaborative project. An evolved LISA mission called eLISA, performed only by European partners is being assessed.

Curiosity about our world and the Universe that surrounds us, has been the driving force behind human progress since prehistoric times. Today, the exploration of space remains one of the most stimulating and exciting areas of scientific research. One of the main initiatives at European and international-collaborative level is the ESA's Aurora programme, which aims to create, and then implement, a European long-term plan for the robotic and human exploration of the solar system, with Mars, the Moon and the asteroids as the most likely targets. All three of these targets are suited to the use of electric propulsion systems for the orbit transfer.

The SMART-1 mission was the first demonstration in Europe of the use of electric propulsion for an exploration-type mission. The mission was a technology demonstrator SMART-1 for solar electric propulsion and other deep-space technologies, while performing scientific observations of the Moon. Among other investigations, mission data provided answers to questions on the origin of the Moon and search for ice in the craters at the Moon's South Pole. The SMART-1 spacecraft was launched in 2003. The SNECMA PPS 1350-G system was used to spiral out to the moon. The mission ended on 3 September 2006 when the spacecraft impacted the lunar surface in the Lacus Excellentiae region. The SMART-1 mission made history with several notable firsts, including: the first electric propulsion mission to escape Earth orbit, the first to use electric propulsion to enter into orbit around another celestial body, and Europe's first lunar mission.

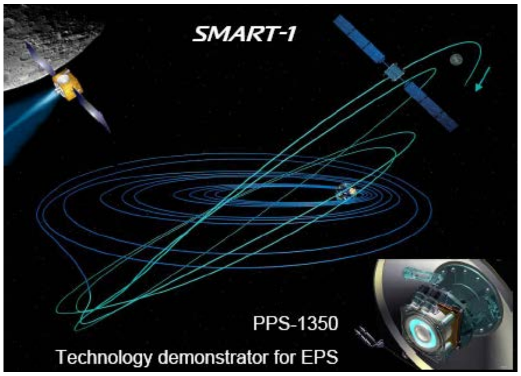

Figure 4: SMART-1 mission

Mars Sample Return mission has been recognised as a major milestone in the exploration of Mars. An ESA internal study, entitled Mars Electric Propulsion (MEP), took the Mars NeXT mission as reference, and aimed to assess the impact of using EP on future missions to Mars. Since this would primarily be a reduction in launch mass, the study baselined a Soyuz launch, rather than the reference Ariane V launch needed for the chemical propulsion case. In addition to this, the study aimed to identify any additional increase in payload mass that could be achieved, while maintaining the transfer duration within the 650 days required for the reference mission. The MEP study has shown that the use of EP for Mars transfer can provide a number of benefits compared to the Mars NeXT reference chemical transfer mission. In particular, the re-use of the BepiColombo MTM based on the T6 GIE system, can provide a 40% increase in payload mass. The transfer can be achieved in 640 days which is comparable to the reference chemical transfer. Although an additional 200 days is required for the Mars orbit capture using electric propulsion, this approach provides significant flexibility in terms of lander deployment, and removes the launch constraint associated with the Mars dust storm season.

Figure 5: Mars Electric Propulsion (MEP) study

The LES3 ESA internal study aimed to provide Europe with a follow on mission to SMART-1 for lunar surface exploration. The objective of the mission was to provide a European technology demonstrator for future lunar and Mars exploration missions (robotic and human) as well as providing a payload platform for specific measurements needed for future lunar exploration. An option to consider EP technologies was assessed and concluded that the use of a high power solar electric propulsion system, perhaps based on re-use of the BepiColombo module, can offer significant improvement in payload mass fraction.

Following the success of GOCE, a Next Generation Gravity Mission (NGGM) is being designed at ESA. This mission is composed of two small satellites flying in formation in a very low orbit. Primary drag compensation would be carried out by the same QinetiQ T5 thrusters used on GOCE. The mini-ion engine from ADS (D) is being considered for compensation of the very small cross track drag forces[3,6].

Finally, a number of feasibility studies and preliminary mission analysis have been and are still being carried out at CNES for Earth observation applications, based on the use of low-power Hall effect thrusters on small (400 kg-class) to medium (1.5 t-class) satellites. Namely, it has been shown that future high resolution missions could benefit from this type of technology, through a broader range of accessible orbits (from 480 km up to 830 km altitude) while being compatible with a VEGA launcher. Besides, low-cost scientific or Earth observation missions on small satellites (400 kg-class) at very low altitude (below 300 km) have been studied for different scenarios that are all made possible by the use of electric propulsion.

D. Space Transportation

Based on growing maturation of electric propulsion systems and increasing capabilities of such propulsion devices (power rising), possible applications to space transportation vehicles have gradually been studied with a more and more detailed level of analysis.
It is possible today to gather the different classes of applications around the two following families of concepts:

- Electric kick stages for launchers to increase performance capabilities
- Service module of Orbital Transfer Vehicles (OTV) for interorbital missions (servicing, cargo transportation beyond LEO, towing of asteroids, etc.)

Several studies have already been performed to increase the performances of launchers by adding an electrical kick stage to a conventional architecture chemically propelled.

-Italian studies evaluated capabilities of the Vega launcher with an electrical kick stage. This study relies on a cluster of five HET engines, each of them delivering a 0.3 N thrust with a 5 kW power requirement. Such a concept would be able to lift a mid-size spacecraft (1000 – 2000 Kg) from LEO to GEO.

-Another possibility has been studied by CNES for implementation in Ariane launchers. EP provides significant increase of performance that can be appreciated for liberation missions for instance. Because of unavailability of higher thrust, the first study only considers cluster of PPS 5000 engines.

Other applicative missions with electric propulsion were also studied as tugs for interorbital servicing. With international effort about electric propulsion, commercial applications are now also examined in detail for maintenance or refueling of orbital objects. Vehicles for cargo supplying beyond LEO are also envisaged to provide heavy loads to far destinations as Mars or its moons. The idea of possible standard service module for interplanetary probes is being also examined. Active Debries Removal missions and Asteroids Retrival missions are also some of the missions that will benefit of an orbital vehicle with electric propulsion (Figure 6).

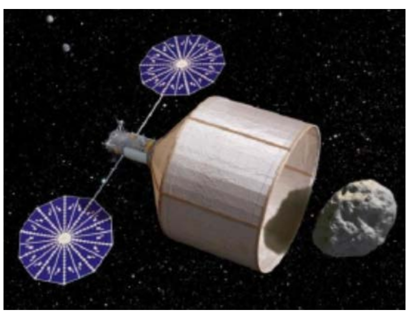

Figure 6 (Asteroid Retrival Mission)

III. Conclusion

This overview of the different applications demonstrates an important potential for electric propulsion systems for future missions. The already promising results would be greatly improved if more powerful engines were available. For kick-stage applications and inter-orbital missions generally the main requirement is to increase the available thrust. For interplanetary probes the search clearly focuses on the maximization of the ISP. For the commercial sector, cheap and reliable systems are required in Europe to compete with other world players such as Aerojet and

Fakel. The European Commission EPIC project within the Horizon 20202 initiative will contribute to improve the competitivity of the European industry working in the space sector.

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