Electric Propulsion at the European Space Agency (ESA)

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Abstract: The high specific impulse of Electric propulsion systems reduces the amount of propellant required to perform an operation in space. These savings will allow space projects to use smaller launches or increasing the payload. In the commercial arena (telecommunication and constellations space missions), the strong competition among satellite manufacturers is a major driver for advancements in the area of electric propulsion, where increasing better performance together with low prices are required. 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 Mercury or Mars and in some cases bring back to Earth samples from these planets. Space tugs, de-orbiting tugs and re-fuelling spacecraft will make also use of Electric Propulsion. Finally, Electric Propulsion systems will be used by the future EVO Galileo programme to perform orbit raising manoeuvres. 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, testing and flight control of the propulsion subsystems of several European satellites. The exploitation of the flight experience is also an important activity at ESA that will help mission designers to implement the lessons learnt to the development of these new propulsion systems. ESA missions such as Artemis, Smart-1, GOCE, Alphabus, Small-GEO and Bepi Colombo have paved the way for the use of electric propulsion in future ESA missions: Neosat, Electra, Mars Sample Return, NGGM, etc.

EP = Electric Propulsion
EPIC = Electric Propulsion Innovation and Competitiveness
FEEP = Field Emission Electric Propulsion
HEMPT = Highly Efficiency Multistage Plasma Thruster
NGGM = Next Generation Gravity Missions

I INTRODUCTION

Since the 1970s, Electric Propulsion was employed on satellites for station-keeping, orbit raising and primary propulsion. It has traditionally had applications for telecommunications and science missions, but increasingly it is now considered for earth observation, navigation and orbit debris removal.

More recently, Cubsats and constellations of small satellites with the mass ranging from 1 to few 100 of kgs are also planning to use to enhance their capabilities. The new cub-sat market assessments envisage thousands of satellites in the next 5 years.

The use of Electric Propulsion (EP) technologies in the Telecommunication space market is today a key issue to improve the position of the European space sector. The European Space Agency in this sector with spacecraft such

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as AlphaSat, Small GEO, Electra or Neosat is preparing the way for the use of this technology in the space telecommunication arena, putting European industries in an advanced position to compete for new telecommunication spacecraft. European primes have won several satellites thanks to the use of electric propulsion not only for station keeping but also for orbit raising (Inmarsat 6-F1, SES-17, Comsat, etc.). Since 2002 European Primes have launched many telecommunication satellites that use electric propulsion for station keeping.

Electric Propulsion (EP) has today extensive development history, testing, and flight experience (Astra-1K, Intelsat-10, Inmarsat-4, Alphasat, Smart-1, Bepi-Colombo, GOCE, Artemis, Alphasat, Small GEO,etc.). Furthermore, the current flight data are proving that expected benefits are real and that future spacecraft missions will enhance their capabilities by using electric propulsion systems (EPS).

II Telecommunications

Commercial GEO telecommunication represents the largest market for electric propulsion. In the last twenty years, these satellites have become more competitive by the adoption of EP for north-south station keeping (NSSK) and Electric Orbit Raising (EOR). Launchers deliver these satellites into Geostationary Transfer Orbits (GTO) and orbit-raising maneuvers to reach GEO are to be performed by onboard propulsion. With Chemical Propulsion, orbit-raising takes up to 1 week but about 50% of satellite wet mass is propellant. With Electric Propulsion, orbit-raising takes between 3 to 6 months depending on the electric propulsion used but launch mass can be reduced by more than 40%. Telecommunication satellites using EP have greater appeal since the propellant mass saved can be used to accommodate larger and more complex payloads [1]. In the last decade, the trend in GEO Telecommunication satellites has consolidated into a considerable increase in electrical power to satisfy the payload needs. The availability of such high power allows for the operation of EP without requiring changes in the platform. On the other hand, the low thrust levels provided by EP systems mean extended firing times and longer transfers to reach the final operational orbit. This implies reduced revenue in the short-term, but important savings in the long-run [2, 3].

In 1997 Boeing made the world's first EP telecoms satellite, PanAmSat,, using XIPS gridded ion engines for station-keeping and chemical thrusters for orbit raise manoeuvres.

Figure 1: ARTEMIS

In 2001, the ESA's ARTEMIS (Figure 1) (the Advanced Relay and Technology Mission Satellite) offered the first European flight demonstration of EP for orbit raising, recovering the satellite to its final orbit following a launcher anomaly.

In 2005, Space System Loral started to use Russian SPT100 Hall Effect Thrusters for station keeping.

In 2010, Lockheed Martin's Advanced Extremely High Frequency (AEHF) satellite after an anomaly with its main Chemical Propulsion system used Hall Effect Thrusters intended for station keeping to complete its orbit raising.

In 2012, Boeing became the first manufacturer to introduce the all-electric spacecraft. All-electric spacecraft have lower mass and enable larger payloads to be carried. It also means that cheaper launchers can be used, or satellites can share a launcher to save costs.

In 2013 Thales and Airbus achieve first flight of Europe's large telecoms satellite, AlphaSat (Figure 2) (Inmarsat-4A 4F), using a set of four SAFRAN AIRCRAFT ENGINES PPS1350 thrusters for station keeping.

In 2014 Airbus wins three orders for E3000 using electric propulsion using HET electric propulsion for orbit-raising.

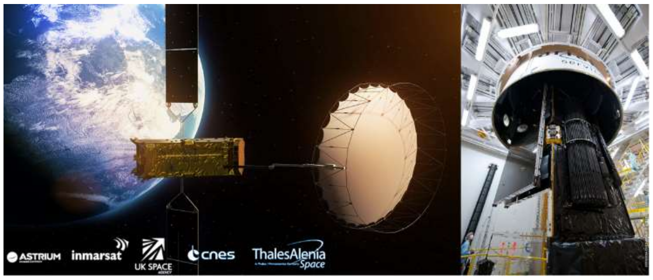

Figure 2: AlphaSAT

In 2015, Boeing successfully demonstrated the world's first all-electric spacecraft using XIPS Ion Engines for station keeping and orbit raising. Mass savings allowed two satellites to be launched by one Space-X rocket.

Since Artemis, ESA and European industries have worked together to further develop electric propulsion technologies. Europe has invested in the development of electric thrusters at SAFRAN AIRCRAFT ENGINES (Hall Effect Thrusters), SITAEL (Hall Effect Thrusters), QINETIQ (Ion Engines), ARIANEGROUP (Ion Engines) and THALES (HEMPT); and these products are now competing with the one available in US and Russia.

European satellite manufacturers have been using electric propulsion for the station keeping of their platforms (Eurostar 3000 produced by Airbus and Spacebus 4000 produced by Thales Alenia Space) for over 10 years accumulating thousands of hours of electric propulsion operations, increasing the confidence in the technology. All of them they are now implementing "all-electric"satellites. By 2020, it is estimated that more than half of all satellites sold will be all-electric or hybrid (embarking both chemical and electric systems).

The ESA-OHB SmallGEO (Figure 3) platform was launched in 2017, equipped with 8 SPT-100 thrusters to fulfil all the orbital manoeuvres for 15 years (station keeping, momentum management, repositioning, end-of-life disposal).

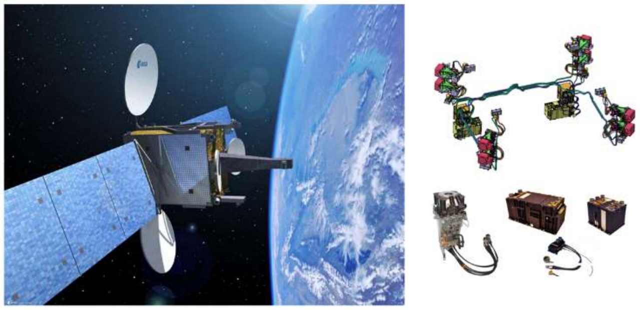

Figure 3: SmallGEO

Airbus DS and Thales Alenia Space are currently evolving their commercial platforms to offer electric orbit raising capability. They are also both currently developing their new ‘all-electric’ platforms, NEOSAT, which will make use of 5kW Hall Effect Thrusters for orbit raising and station keeping.

In 2017, EUTELSAT 172B satellite, an “all-electric” built by Airbus DS reached geostationary orbit in record time by using the 5kW Hall Effect Thrusters.

OHB is also developing its ‘all Electric’ platform, Electra [4], which will make use of 5kW Hall Effect Thrusters for orbit raising and station keeping.

Navigation

The European Galileo Second Generation (G2G) satellites are expected to use EP to orbit raise the satellites from their injection orbit to their final operational orbit. The use of EP would also allow to increase payload capability and to deploy high performing satellites to different orbit planes in a single launch. The full exploitation of launch vehicle capabilities and the design of efficient transfer trajectories are major components of developing an efficient deployment strategy for Galileo. Multiple satellite configurations are currently been studied to find solutions which satisfy accommodation requirements of the payload, solar arrays and propellant, demonstrate sufficient mechanical and thermal performance, support the desired level of modularity and ensure the ability to fit multiple spacecraft on European launchers. As the selection of Electric Propulsion thruster has a large impact on the satellite design, detailed trade-offs are still being carried out to analyse combinations of thruster type, number and operating point in order to optimise satellite design with an acceptable transfer duration, to ensure failure robustness and technical maturity.

Science & Exploration

The use of electric propulsion for scientific spacecraft is recognised as an important way to enhance mission performances. Replacing or augmenting chemical propulsion with electric thrusters as the primary propulsion system can bring the following benefits:

- an increase in net payload mass
- a reduction in flight time with respect to mission based on chemical propulsion and complex gravity-assisted operations
- independence from launch-window constraints, which are imposed by the classical gravity-assisted planetary fly-by operations
- possibility to use small/medium launch vehicles (providing substantial launch-cost savings).

Specific mission requirements, in terms of power availability, satellite mass and mission profile, dictate the choice of the particular EP technology to be used.

Deep Space 1 was the first use of EP on an interplanetary mission, and its main objectives, the flyby of asteroid Braille and Comet Borrelly, were successfully performed by NASA's NSTAR ion engine in the late 1990s. The JAXA science mission Hyabusa used Japanese ion engines to rendezvous with an asteroid in 2005.

Figure 4: SMART-1

ESA's first Moon mission, SMART-1 (Figure 4), paved the road to the use of EP on European Science and Exploration missions. The mission was technically and scientifically a success, helping ensure Europe's technology competence in this promising technology and in Lunar exploration. The relatively small satellite, equipped with one PPS-1350G HET from SAFRAN AIRCRAFT ENGINES, required only 82 kg of Xenon to reach and orbit the Moon.

ESA's cornerstone missions BepiColombo will provide the best understanding of Mercury to date by studying and understanding the composition, geophysics, atmosphere, magnetosphere and history of Mercury, the least explored planet in the inner Solar System. BepiColombo (Figure 5) is propelled by a cluster of several kW T6 Gridded Ion Engines developed by QinetiQ.

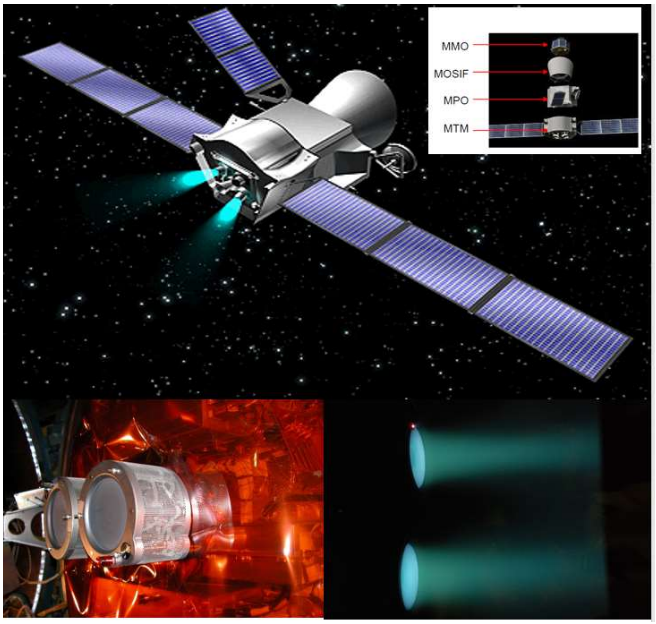

Figure 5: BepiColombo

Future scientific missions such as LISA (Laser Interferometer Space Antennas) (Figure 6) will require electric microthrusters as very fine control actuators to insure operation under drag-free conditions. These thrusters should also have a long lifetime and FEEP, colloidal thrusters and miniaturized ion engines are main candidates to this kind of missions together with cold gas thrusters flown in Lisa-Pathfinder.

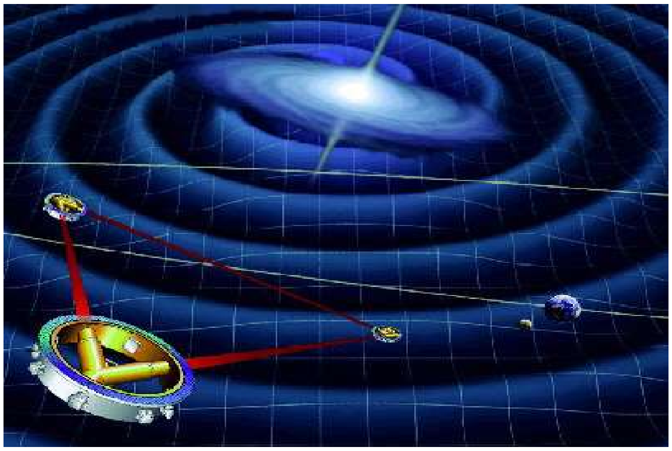

Figure 6: LISA

ESA and European industries have also assessed the use of EP for missions to Asteroids. Marco Polo had the objective to return samples from a near Earth asteroid, while providing context information on the Asteroid itself. Unfortunately, this mission was not selected for further implementation.

ESA is currently studying the future evolution of the Exploration programme and is assessing the possibility to implement a technology mission that allows testing future technologies required for exploration missions. High-power EP (15-20kW) is considered perfect candidate to perform interplanetary cruise. Initiatives such as CISLUNAR will require 12.5-20 kW Hall Effect thrusters to keep the station around the Moon and/or transfer it to Mars. The first European prototype of a 20kW Hall Effect Thruster was built and tested in the frame of the HiPER project ("High Power Electric propulsion: a Roadmap for the future") co-funded by the European Union under the space theme of the 7th Framework Programme. Since 2015, ESA is also funding the development of a 20kW Hall Effect at SITAEL S.p.A.

The Mars Sample Return Mission (Figure 7) may use ion engines for the 3rd mission to recover the sample and bring it back to Earth.

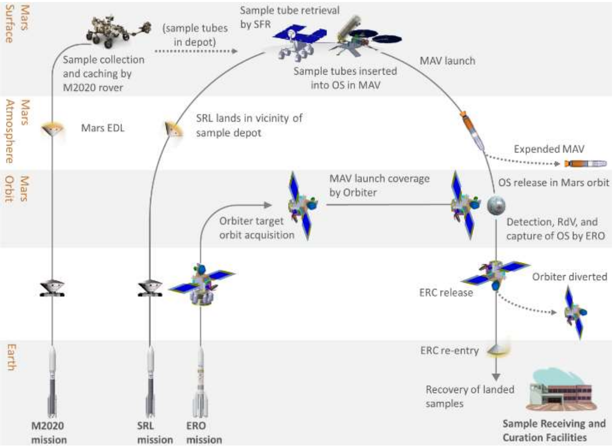

Figure 7: Mars Sample return

Earth Observation

Earth Observation missions, like GOCE (Figure 8), also benefitted from the use of EP. The main aim of the GOCE mission was to provide unique models of the Earth's gravity field and its geoid to high spatial resolution and accuracy. The T5 GIE system from QinetiQ was operated on GOCE almost continuously from 2009 to 2013 to compensate aerodynamic drag. 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.
Next Generation Gravity Missions (NGGM) is considering miniaturised GIE from ARIANEGROUP and FEEP from FOTEC/ ENPULSION to compensate drag 5.

Figure 8: GOCE

Furthermore, the use of small ion engines, small Hall Effect thrusters, FEEPs or helicon antenna thrusters would enable operation of earth observation satellites at much lower altitude orbits [7].

There has been studies and development programs considering the use of the gases in the atmosphere as propellant for electric thrusters (RAM-EP) to enable continuous operation at altitudes lower than 200 km. Finally, constellation of thousands of satellites are currently been developed. These satellites are launched in cluster and need low power EP to reach their operational orbit, stay there and be disposed at the end of the mission. Cheap and versatile electric propulsion systems will be required as the cost of the system shall be one order of magnitude lower than current prices.

Space Transportation

Based on growing maturation of electric propulsion systems and increasing capabilities of such propulsion devices, 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 (e.g. Electric-Vega);
- Space Tugs for GEO servicing, LEO/MEO Debris Removal, LEO/MEO to GEO tugging and Moon cargo delivery.

CubeSats

Numerous EP micro-propulsion systems are currently under development in Europe to enhance the performance of CubeSats by enabling drag compensation, orbit keeping, formation flying, orbit transfer and de-orbiting at end of life. Their compactness, good performance and low price are increasingly appealing as the space industry interest in small satellites with mass ranging from 1 to few 100 of kg grows all over the world. These satellites, often in constellation, could provide commercial services such as global internet coverage and monitoring of air and sea traffic or Earth observation to broadcast weather and monitor the response to natural disasters.

A miniaturized version of the Indium FEEP thruster for CubeSats and small satellites, the IFM Nano thruster (Figure 9), is under development at Enpulsion and FOTEC (A) to provide highly accurate thrust ranging from 10 µN to 400 µN @ 40W with an Isp up to 6000s.

A Pulsed Plasma Thruster (PPT) for CubeSats, PPTCUP, is being developed by a consortium led by Mars Space (UK) to provide thrust of 40 µN @ 2W with an Isp of 600s.

A consortium led by Queen Mary University (UK) is developing a very compact and highly efficient Electrospray Colloid EP system.

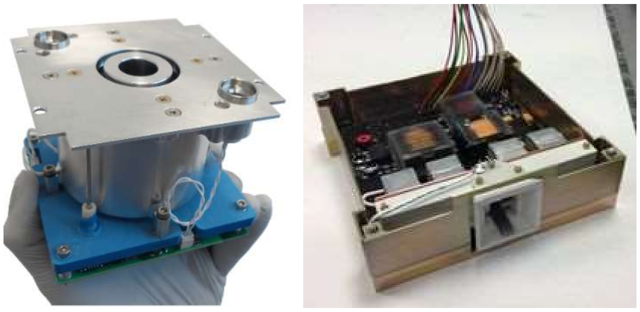

Figure 9: IFM Nano Thruster (left), PPTCUP (right)

EPIC

The European Commission is currently contributing "*to guarantee the leadership of European capabilities in electric propulsion at world level within the 2020-2030 timeframe*" via their H2020 grant titled "Electric Propulsion Innovation and Competitiveness", in short EPIC. The grant is structured along the two lines of Incremental Technologies and Disruptive Technologies. ESA is the coordinator of this project where the team is formed by several space agencies and industrial entities.

Incremental Technologies are the most mature technologies having flight heritage, with the physical principal well understood, and with established performances. They are the Hall Effect Thruster (HET), the Gridded Ion Engines (GIE), and the High Efficiency Multistage Plasma Thrusters (HEMPT). Under EPIC, these Incremental Technologies shall improve their current performances and reduce their cost in order to increase their competitiveness in the global market.

Disruptive Technologies are very promising EP concepts which could disrupt the propulsion sector by providing a radical improvement in performance and/or cost reduction, leading to become the preferred technology for certain applications/markets or enable new markets or applications not possible with the existing (Incremental) technologies.

The selected Incremental Technologies contracts are: CHEOPS on HET; GIESEPP on GIE and HEMPT-NG on HEMPT technologies.

The selected Disruptive Technologies contracts are: GaNOMIC on PPU innovative Technologies; HiperLoc-EP on Electrospray Colloid EP System and MINOTOR on Electron Cyclotron Resonance Accelerator thrusters.

CONCLUSIONS

Since the 1970s, Electric Propulsion has been used on satellites for station-keeping, orbit raising and primary propulsion. It has traditionally had applications for telecommunications and science missions, but increasingly the use of EP is being considered for earth observation, navigation and space transportation.
More recently, constellations of small satellites (e.g.SpaceWeb, Starlink, LEOSAT, etc.) are being designed to use electric thrusters to perform the transfer to the operational orbit and other functions. Thanks to the mass savings made possible by the use of electric propulsion, fewer launchers are needed to place the constellation in orbit, thereby allowing a major cost reduction for the service being offered. The use of EP is also capable to enhance the services offered by CubeSATs.

Europe has excellent capability in the area of Electric Propulsion, which has stemmed from decades of research and development and exemplified by the success of ESA missions such as ARTEMIS, SMART1, GOCE, AlphaSAT and small GEO that have paved the way to the use of electric propulsion on BepiColombo and European commercial telecom satellites such as Neosat and Electra.

A big effort is now being made on industrialisation and price reduction to guarantee the competitiveness of European EP products in the global market. The first positive result is the orders made in 2017 by US Boeing satellites of European EP systems such as the PPS5000 from SAFRAN AIRCRAFT ENGINES (F) and the RIT2X from ARIANEGROUP (D) [8].

The European Space Agency together with National Space Agencies and European satellite prime contractors have already identified electric propulsion as a key technology for the new generations of commercial and scientific satellites. The ESA Propulsion Lab is an important tool to support industry in the development of new and current EP systems [6].

ESA is strongly involved and committed in this technology area, both as an initiator of electric propulsion system developments and a user of this technology for its new missions. The goal is to maintain the competitiveness of European industry by ensuring the availability of qualified, cost-effective and reliable EP systems, and to make new and challenging scientific missions possible. The European Commission through the EPIC H2020 programme is also helping to get this task.

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