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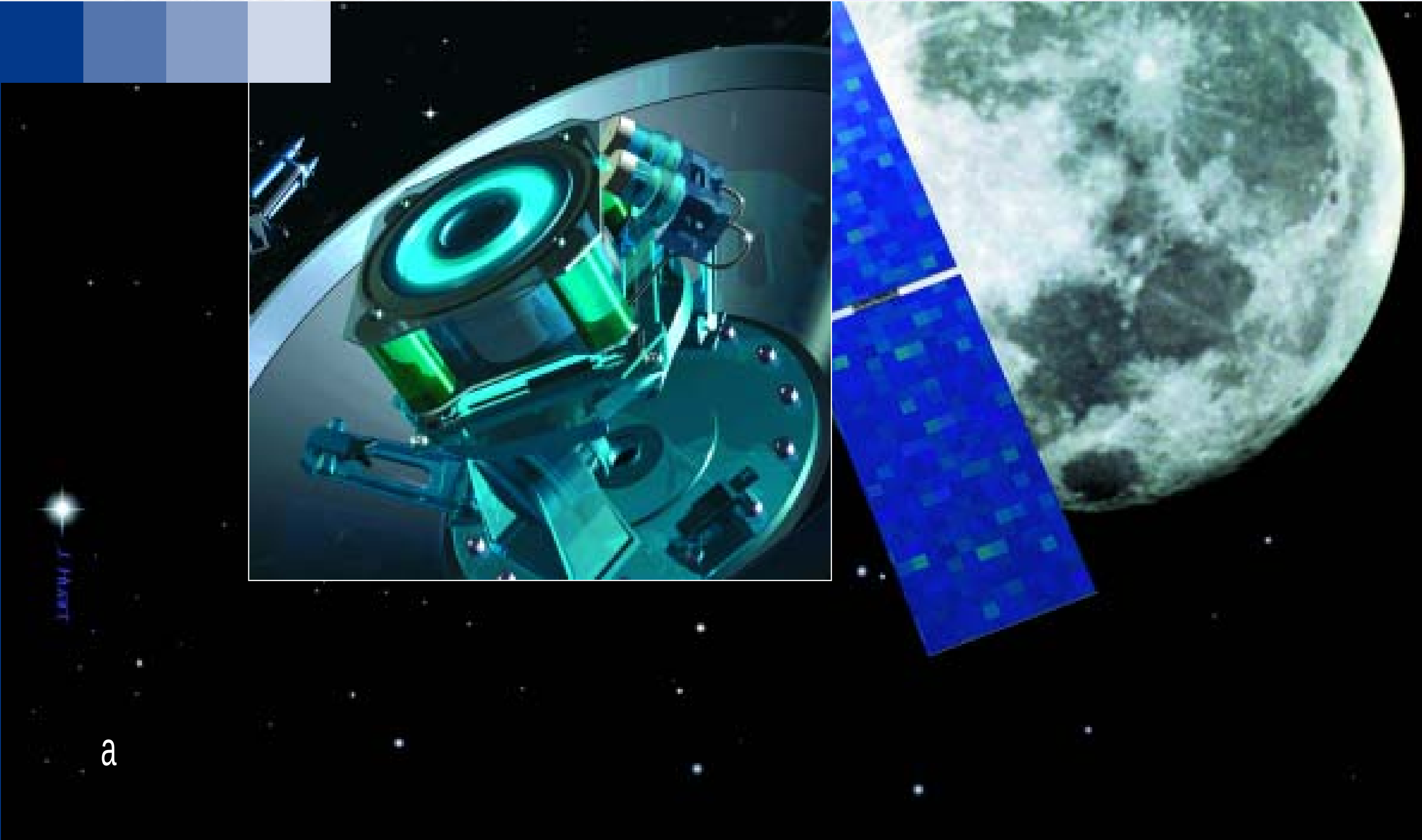
ELECTRIC PROPULSION

Technology Programmes



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Introduction

The success of a space mission is always linked to the performance of technology. To have a technology ready when a satellite flies, research and development must start years in advance. This is the objective of the Technology Programmes of the European Space Agency: to ensure effective preparation for European space activities.

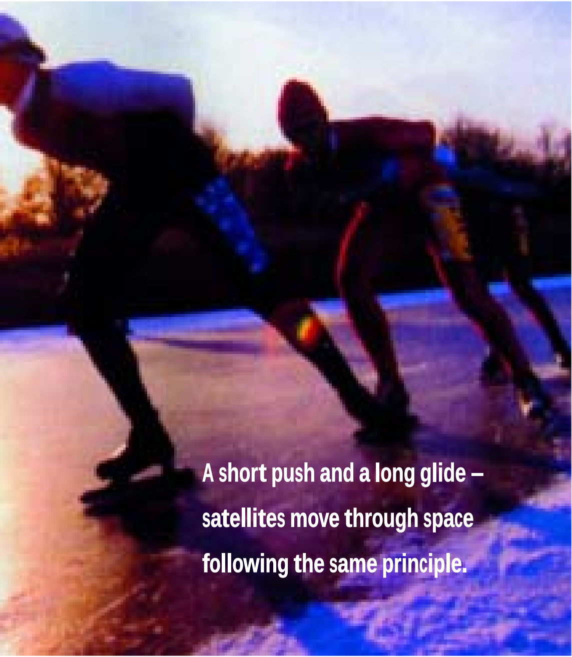
Electric propulsion is a good example of space technology. This brochure will give you many examples of how it works on a spacecraft, and what challenges it overcomes.

I hope it will let you share the enthusiasm of the engineers who wrote the stories. Above all, I hope it will help you to appreciate the efforts of all the European engineers who work behind the scenes of space projects, not only in the area of electric propulsion, but in also in many other fields. Without their hard work, Europe's success in space would not have been possible.

Jensen

Niels E. Jensen

Head of the Technology Programmes Department



A short push and a long glide – satellites move through space following the same principle.

Satellites are subject to the gravitational fields of celestial bodies. The fact that they attract each other has been known since Kepler's time.

Moving around in space

All satellites need a means of moving through space, and their usual way of travelling resembles that of skaters: a short push and a long glide. All satellites move along orbits, as they revolve around a celestial body. Most satellites are in orbit around the Earth, while others orbit the Sun or are in orbits specifically designed to bring them close to a comet, a planet or its moons.

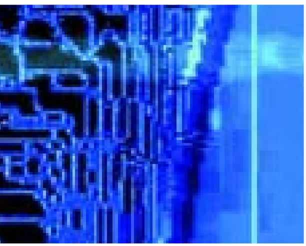
It may seem strange at first, but everywhere in the Universe a body is subject to the gravitational pull of other nearby celestial bodies. So whenever something is moving, apparently freely in space, it is in fact subject to the gravitational attraction of a planet, a star, a galaxy or a group of galaxies. All bodies attract each other – which one wins is just a matter of their sizes and the distances between them.

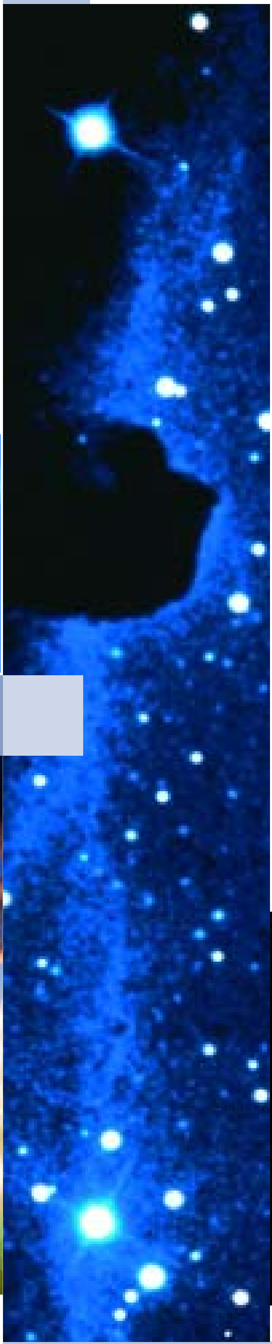
To escape from the attraction of, say, Mars and leave an orbit around it, a spaceship would have to accelerate to a velocity sufficient to counteract the planet's gravitational pull, or more precisely its gravitational field. Having made this effort, it would then start 'feeling' the pull of the Sun and would have to increase its velocity still further to escape from its influence too. The problem is that such high accelerations require a lot of energy, much more than is available on today's satellites.

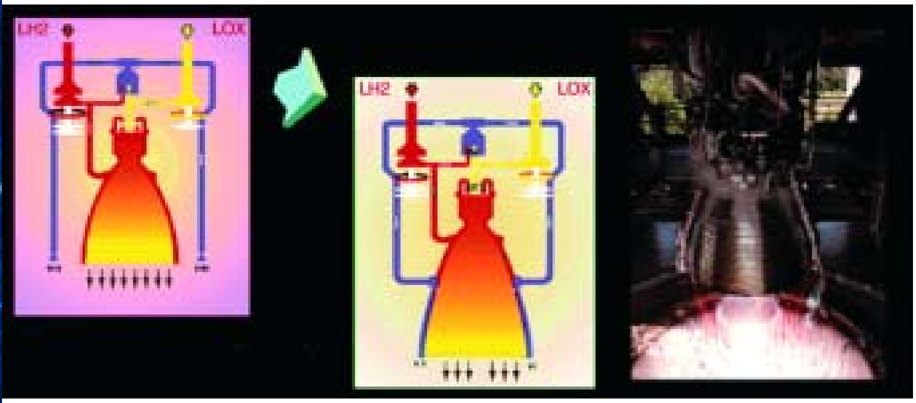
How do satellites move?

How do satellites reach their initial orbits from the ground? And how do they move from one orbit to another? The journey of any satellite starts aboard some type of rocket-propelled vehicle, which is the only means available today for transporting it into space and overcoming the strength of Earth's gravitational field. The rocket usually puts the satellite into an initial (or 'transfer') orbit just a few hundred kilometres above the Earth's surface; even the Apollo capsules began their journey to the Moon by first being placed into Earth orbit by the powerful Saturn rockets. It is then up to the satellite to propel itself, often with the help of a so-called 'upper stage', into its final operating orbit.

To be able to move when necessary to another orbit, be that still around the Earth or across the Solar System, satellites are equipped with small thrusters. In space there is nothing against which you can push, and so the only way to achieve movement is through reactive forces. It is like being stuck in the middle of a frozen pond with no way to move on the slippery ice. If you are lucky enough to have a heavy rucksack, throwing it away in front of you will push you in the opposite direction, hopefully making you glide to the edge of the pond. Satellites do the same, ejecting matter in one direction and moving in the opposite one.





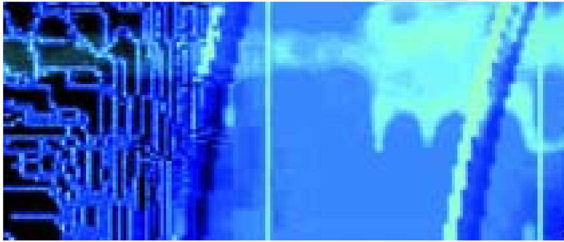


Below right: An Ariane-5 Vulcain engine firing and the principles of the engine's operation

How does propulsion work?

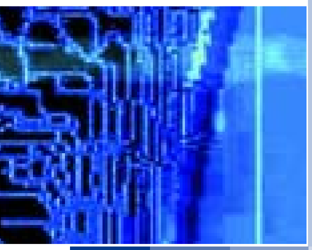
Today there are basically two means of propulsion. The first and most common one, chemical propulsion, uses chemical reactions to produce a flow of fast-moving hot gas, thereby providing a strong push. The second uses the electrical power that can be generated from sunlight with solar photovoltaic panels to propel the spacecraft by more efficient means.

Let's start with chemical propulsion, which is not that different from a car or jet engine. You need one or two substances that can be burned in a controllable way. The combustion takes place in a chamber and the resulting very hot gases are ejected through an opening, the nozzle, to provide the desired thrust. Heating the gas in a chamber produces an increase in pressure and letting it escape through a small aperture produces a very fast jet. By varying the amount of fuel burned and the shape of the nozzle, which controls the velocity of the exhaust gases coming out of the engine, or thruster, one can cater for many different needs, ranging from the launching of a huge rocket to the manoeuvring of a tiny satellite. The real difference compared with car and jet engines is that in space thrusters must work without the oxygen present in the Earth's atmosphere, which is a fundamental ingredient in most combustion processes.

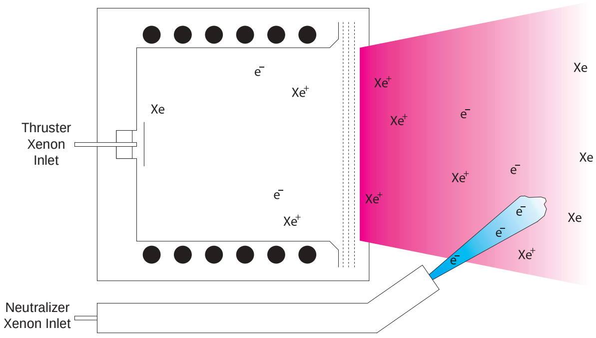


The big problem with chemical propulsion is that, whilst it is capable of producing an enormous thrust, sufficient for example to lift huge rockets off the ground, it is quite a complex process. For instance, when liquid propellants are used, which is usually the case, it requires very complicated systems, with tanks, pipes, valves and very delicate control mechanisms. As the propellant is highly inflammable, it is also quite a dangerous business.

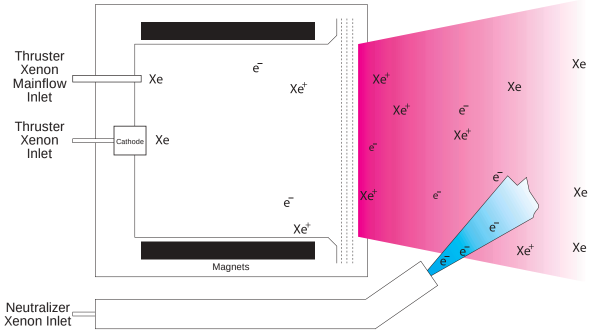
What exactly is electric propulsion?



The working principles of two different types of electromagnetic thrusters (gridded ion engines)

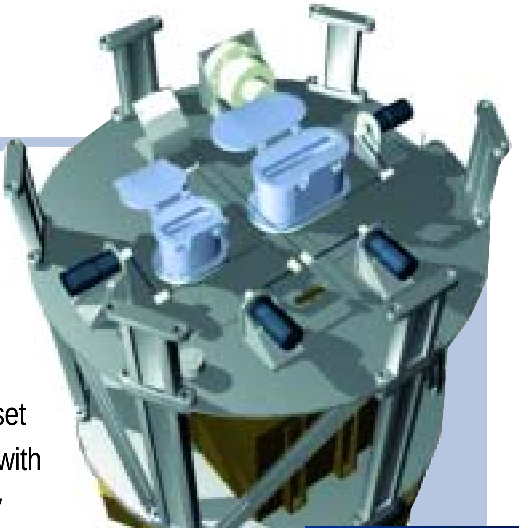


Electric propulsion is a generic name encompassing all of the ways of accelerating a propellant using electrical power. The simplest way to achieve electric propulsion is to replace the heat generated by combustion in chemical engines with electrical heating. Placing your pressure cooker on the hotplate of an electric cooker is a perfect example of how they work. Another way to heat a stream of gas is to use a controlled electrical discharge (arc). However, there are other, more sophisticated and more efficient ways of obtaining fast jets of gas!



One of the classical ‘home science’ experiments is to lift a small piece of paper with a plastic rod (usually a ballpoint pen) after rubbing it against a woollen material – the rod becomes electrically charged and attracts the paper. If it doesn’t work, either you did not rub enough (i.e. you did not charge it enough) or the plastic of your pen is too conductive (i.e. it loses the charge too quickly). Now, imagine that instead of a plastic rod you have a grid with relatively large holes, and instead of a piece of paper you add a lot of tiny balls. The balls will float towards the grid and the force attracting them (i.e. the pull of the static electric field generated by the charged grid) is proportional to the charge on the grid. Increasing the charge will cause the balls to move towards the grid with greater acceleration and reach it at a higher speed. If the speed is made sufficiently high, most of the balls will just pass straight through the grid and continue on their way. This is how electrostatic propulsion works. The tiny balls are ionised particles of propellant and the fleet of particles launched past the grid pushes the satellite (or space vehicle) in the opposite direction.

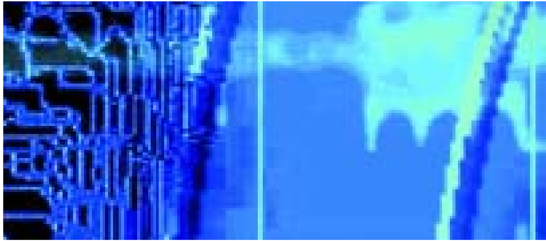
Another possibility is to use the combined effect of an electric field to set the particles in motion and a magnetic field to accelerate them. While with the use of an electric field alone, only charged particles of one polarity (opposite to that of the grid) provide propulsion, with the combined action of electric and magnetic fields both polarities are accelerated.



The FEEP flight experiment assembly on a Shuttle Get-Away Special

The PPS-1350 Hall-Effect thruster (courtesy of SNECMA)

The actual working of magneto-electric thrusters is a little more complex. Charged particles are set in motion – in opposite directions – by the electric field. A magnetic field has an effect on a moving charge known by physicists as the ‘Lorentz force’, similar to that which an electric field has on a stationary charge: it pulls the charged and moving particle sideways. By combining the effects of the electric and magnetic fields, the flow of charged particles is accelerated and ejected by the thrusters, producing the desired push.



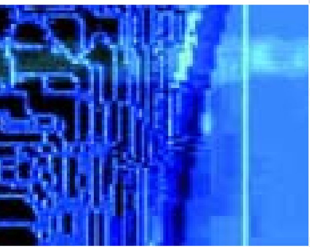
The various types of thrusters are characterised by different performances. Some types are more suitable for missions requiring higher thrust levels to reduce the trip time, some are better for high-precision positioning applications, while others use a minimum of propellant. The propellant employed varies with the type of thruster, and can be a rare gas (i.e. xenon or argon), a liquid metal (i.e. caesium or indium) or, in some cases, a conventional chemical propellant such as hydrazine or similar substances (e.g. ammonia, nitrogen).

The FEEP thruster in its protective container (courtesy of Centrospazio/ALTA)

Electric propulsion is not a new concept, having been studied in parallel with chemical propulsion for many years, and science-fiction writers have always been fascinated by it. The most famous spaceships in the SF literature are powered by electric-propulsion engines, like the ‘Discovery’ in the film ‘2001: A Space Odyssey’. The reason why it has come to practical application only recently lies in the low amounts of electrical power available onboard real spacecraft. The increased efficiency of today’s electric-propulsion thrusters, combined with the much greater electrical powers available on today’s spacecraft, has made the use of electric propulsion a reality.

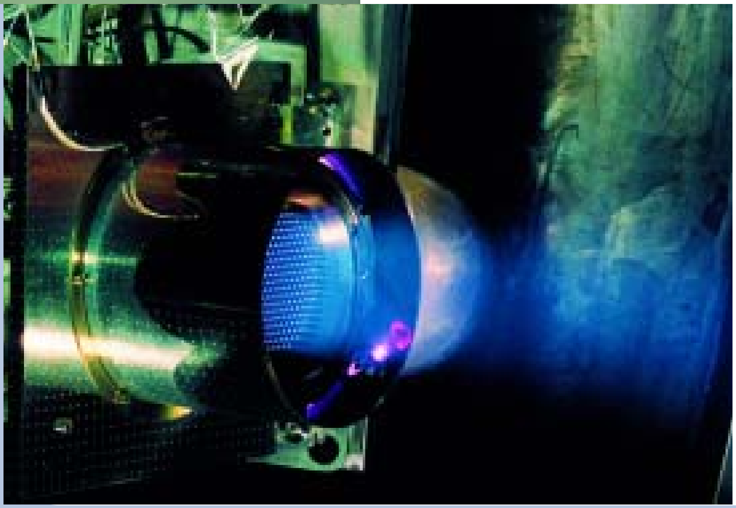
Why is it better?

Electric propulsion offers several advantages. First it is safer. Electric-propulsion engines are also more efficient than chemical ones, in the sense that they require much less propellant to produce the same overall effect, i.e. a particular increase in spacecraft velocity. The propellant is ejected up to twenty times faster than from classical thrusters and therefore the same propelling force is obtained with twenty times less propellant. The only negative point is that chemical engines can eject massive amounts of propellant, while electric thrusters work with very small flows, so that they push the spacecraft very gently compared with chemical systems – comparable with the reactive force generated by an ant walking on a sheet of paper! Consequently, it takes much longer to achieve a particular speed and hence when high acceleration is critical electrical propulsion cannot be used, at least in its current forms. On the other hand, the force it produces can be applied continuously for very long periods – months or even years! For interplanetary missions, therefore, the target destination can sometimes be reached more quickly than with chemical propulsion.



The Artemis satellite and its ion thrusters. Electrical power generated from sunlight propels the spacecraft

Electric thrusters also give the ability to regulate the force applied to the spacecraft very accurately, making it possible to control the spacecraft's position and orientation along its orbit with incomparable precision. More sophisticated high-precision scientific missions, such as gravitational-wave detectors, space interferometers and advanced space observatories being developed by ESA and NASA will rely on these unique characteristics of electric propulsion for their success.



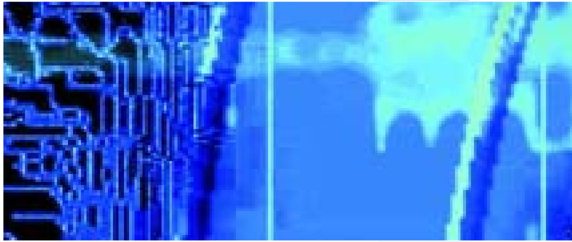
The RIT-10 Gridded Ion Thruster (courtesy of Astrium)

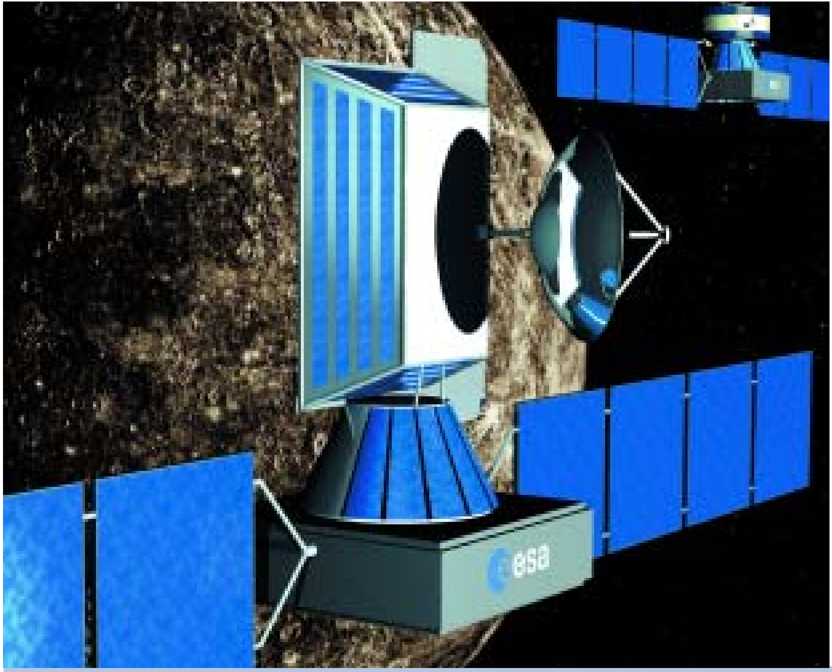
How far can you go with electric propulsion?

Today's most important applications of electric propulsion are on geostationary telecommunications satellites, such as ESA's Artemis, where the technology is used to move the satellite from its initial transfer orbit to its final orbit around the Earth and to maintain that orbit throughout the satellite's operational lifetime (10-15 years), by compensating for the gravitational perturbations induced by the Earth, the Moon and the Sun. The use of electric propulsion on a modern telecommunications satellite easily provides a saving of more than 20% in the initial launch mass.

The second important use of electric propulsion is for interplanetary probes, such as ESA's SMART-1 and Bepi-Colombo missions (to the Moon and the planet Mercury, respectively), where electric propulsion provides the primary source of thrust for transporting the satellite to its final destination.

The coupling of electric propulsion with powerful electrical power sources, such as nuclear generators, will open the way for the exploration of the Solar System and beyond. Large manned and unmanned space platforms will be gently, but continuously, accelerated to reach the most distant bodies in our Solar System in acceptable travel times. Human colonization of the Sun's planets and their satellites will be made possible through the use of this propulsion technology.





Bepi Colombo

SMART-1

Europe to the Moon

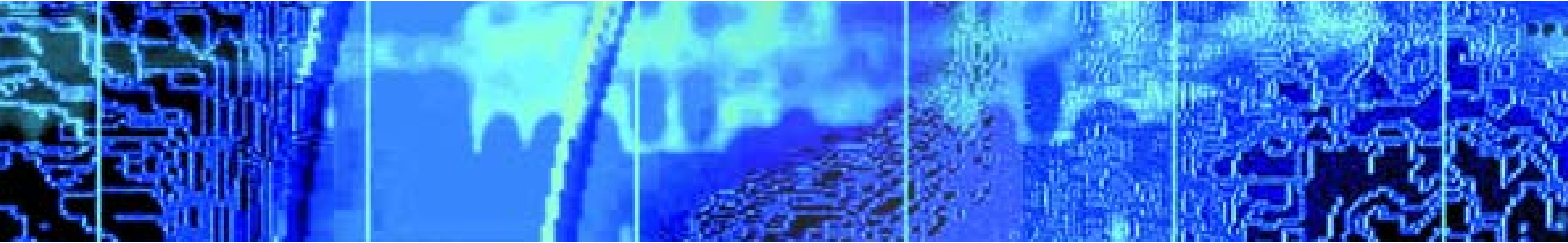
The European Space Agency is ready to send an unmanned high-tech spacecraft to the Moon.

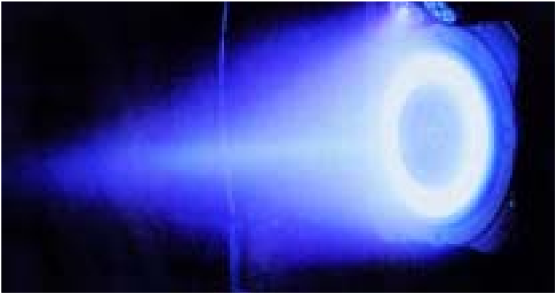
The low-cost SMART-1 mission is the first of several innovative test flights to demonstrate the use of new technologies to be applied on future deep-space missions, such as a voyage to Mercury. For the first time, Europe will use solar electric propulsion with a futuristic “ion beam” as the primary propulsion. SMART-1 will be the first ESA spacecraft to orbit the Moon.

The small lunar orbiter will be launched as an auxiliary payload on a standard Ariane–5 commercial flight. Once deployed, the spacecraft will use solar electric propulsion to escape Earth’s gravity and to power its multi-month cruise to the Moon. In addition to its new electric engine and associated equipment to monitor its performance, SMART-1 will carry several innovative science instruments to study the Moon, including an X-ray spectrometer, an infrared spectrometer and a micro-imager which promises to send back startling pictures during the six-month observation period.

SMART-1 will employ a compact engine called a Stationary Plasma Thruster (SPT) which uses xenon gas as a propellant. Electrical solar power will be used to ionise and expel the gas at high speed, generating, by reaction, the movement of the satellite. The unit is a Stationary Plasma Hall-effect thruster, the PPS-1350 developed by SNECMA, France.

The cruise to the Moon will take 14-18 months, depending on the launch date.





SMART-1 Mission Summary

Characteristic’s	Three-axis stabilised spacecraft, consisting of a cube-shaped platform with 1 m side carrying the propulsion systems and the technology and science payload. Two solar wings with a 14 m span will provide electrical power. A Stationary Plasma Thruster (PPS-1350) with a nominal 70 mN thrust will provide the primary propulsion. The launch mass will be 350 kg.
Trajectory	Delivered by Ariane-5 in a Geostationary Transfer Orbit (GTO), SMART-1 will use Electric Primary Propulsion to spiral out to the Moon by means of a low thrust optimised trajectory. It will also make use of celestial mechanics “tricks” like “Moon resonances” and swing-bys. The spacecraft will exploit those unstable regions of space where the gravity field of Earth and the Moon compete and which are normally avoided by conventional trajectories.
Launch window	From October 2002 to October 2003.
Operational Orbit	Elliptical lunar polar orbit, 300-2000 km above the Moon’s South pole at its closest, to 8000-10 000 km at its furthest distance

The Technology of Space Exploration

Satellites

Electric propulsion is only one of the many kinds of technology developed for satellites and space missions.

What is space technology all about? Why are satellites as they are?

Satellites are extremely complex and expensive – each one costs millions of Euros – because they have to work and survive in space for up to 15 years. To make this possible, a satellite has to produce its own power, generating electricity from sunlight falling on photovoltaic cells or solar panels. Batteries are used to store the energy, so that the satellite can continue to work when the Sun is eclipsed or far away – for example during a mission to visit a comet or a distant planet.

To position itself in space, a satellite has to manoeuvre using its own small rocket engines. It also has to keep its orientation, using thrusters or gyroscopes, otherwise it will tumble along its orbit and its antenna will drift out of alignment with the Earth. Space is not a friendly environment, either. Satellites have to survive temperature variations of more than 100ºC – rather like someone standing in front of a fireplace with a blazing fire while an air conditioner pumps freezing air onto their back. Outside the protection of the Earth's atmosphere, the level of radiation (UV, X-rays, gamma rays and all sorts of energy particles) is much higher and more destructive than on the ground.

Before they can even begin to operate in space, satellites have to survive the bone-shaking launch. Then the solar panels have to be opened and antennas, which are often stowed to take less space in the launcher, deployed before the satellite enters its operational orbit. Once in orbit, a satellite usually carries out multiple functions, with different payloads or instruments. It then sends information to a ground station about the condition of its payload and its systems, and it receives instructions back from the ground operators. All this has to work well, with little possibility of recovery, not to mention repair. Apart from the very special cases, there is no way back. Unlike other kinds of business, efficiency and durability are not just an advantage – they are essential. This is why it takes years of work by many talented engineers to design, build and check the correct functioning of a satellite. This is what space technology is all about.

ESA Technology Programmes

Without the availability of suitable technology, the successful exploration and exploitation of outer space would be impossible. The eventual success or failure of a space mission may ultimately be decided by the performance of one piece of technology – an antenna for telecommunications, a radar to observe the Earth, or special lenses for a space telescope. Each individual component is crucial. To have a technology ready when a satellite flies, Technology Research and Development (TRD) must start years in advance. The scale of this activity can be judged by the fact that, each year, ESA manages TRD contracts worth around 250 million Euro.

Preparing for the future

ESA ensures that Europe is technically prepared for the needs of future satellite programmes. This involves establishing a skilled workforce and making European industries more competitive on the World markets, for instance by reducing costs and development time. In some areas of technology, such as launch vehicles, antennas or solar cells, Europe has achieved World leadership.

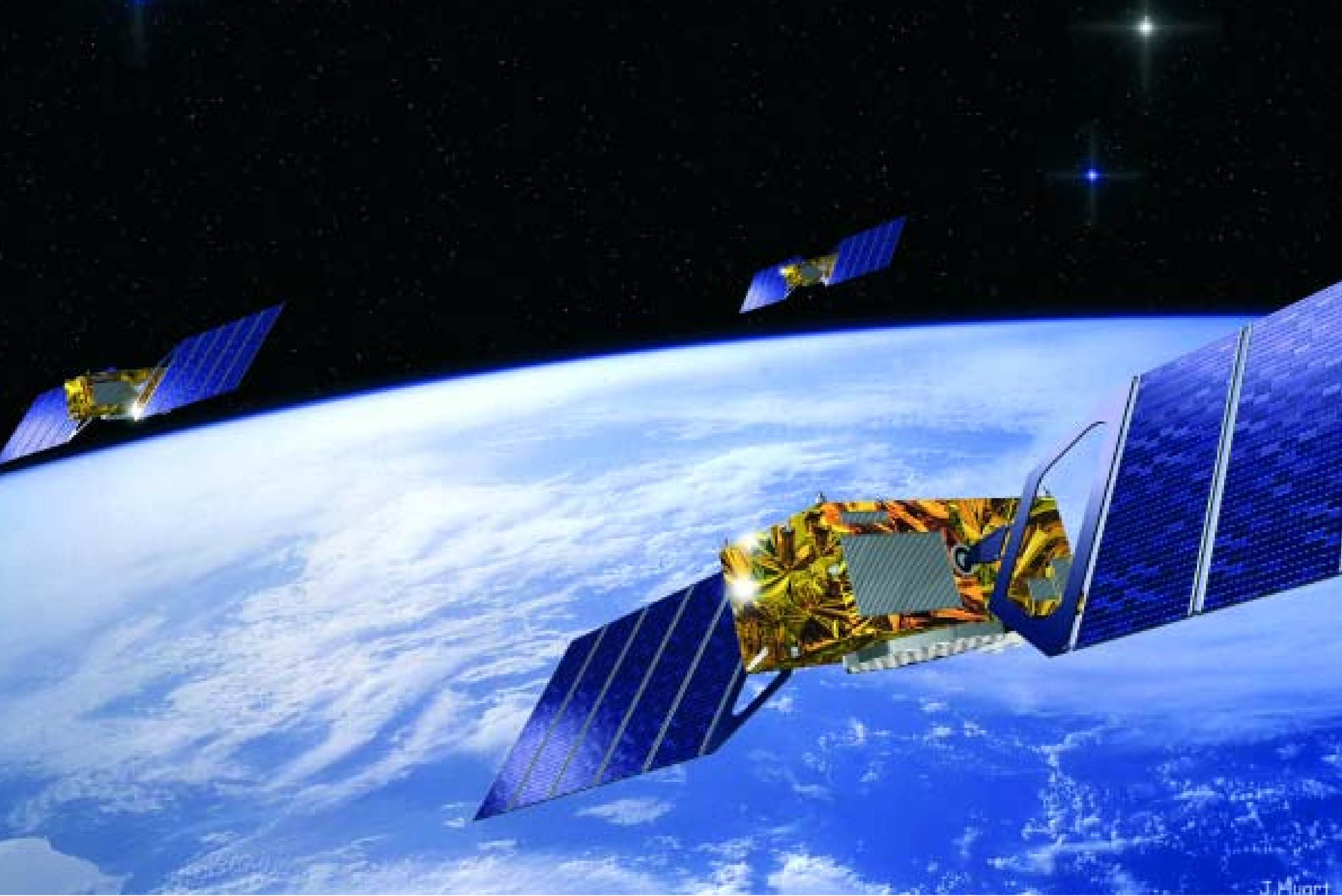
Innovation: targeted technical breakthroughs

New ideas are vital to progress and success. In addition to the technologies needed by markets in the short term, Europe also invests in the research for the longer term. In this way, Europe lays the foundations for new services and products. Some of these may still be in the early stages of development, while the potential of others may not yet have been recognised. However, such research may eventually open up entirely new scientific and commercial opportunities.

Careful planning

ESA fosters a balanced European space industry, so that the expertise needed to develop space programmes is distributed in a balanced way. As a result, all strategic areas in satellite development are covered, avoiding overlaps between countries or among the activities of the national governments and the EU. In addition, ESA encourages small and medium industries, facilitating their access to space activities and granting them a technically rewarding role in the Agency's exciting and innovative space programmes.

Space promotes an industry of innovation and high added-value services, fostering economic growth and employment.



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