Ion thrusters for future Mars and Mercury Missions, Military Satellites and Spaceplanes

An ion thruster is a form of electric propulsion used for spacecraft propulsion. It creates thrust by accelerating ions with electricity. As the ionised particles escape from the aircraft, they generate a force moving in the other direction. Power supplies for ion thrusters are usually electric solar panels, but at sufficiently large distances from the sun, nuclear power is used. Ion thrusters are categorized by how they accelerate the ions, using either electrostatic or electromagnetic force. Electrostatic thrusters use the Coulomb force and accelerate the ions in the direction of the electric field. Electromagnetic thrusters use the Lorentz force.

Ion thrusters achieve high specific impulse—ratio of thrust to the rate of propellant consumption, or propellant mass efficiency, by accelerating the exhaust to high speed .The high specific impulses significantly reduce the propellant requirement for a given mission than would be needed with chemical propulsion. A xenon based EPS can be five to six times more efficient than chemical-based propulsion on spacecraft and has many uses, according to Dr Annadurai, whose centre assembles all Indian spacecraft. A 3,500-kg EPS-based satellite, for example, can do the work of a conventional spacecraft weighing 5,000 kg, but cost far less.

However Ion thrust engines create small thrust levels (the thrust of Deep Space 1 is approximately equal to the weight of one sheet of paper) compared to conventional chemical rockets. They are practical only in the vacuum of space and cannot take vehicles through the atmosphere because ion engines do not work in the presence of ions outside the engine. Besides, the engine's minuscule thrust would not matter when air resistance comes into play.

Ion thrusters are being designed for a wide variety of missions—from keeping communications satellites in the proper position (station-keeping) to propelling spacecraft throughout our solar system. "Ion propulsion is even considered to be mission enabling for some cases where sufficient chemical propellant cannot be carried on the spacecraft to accomplish the desired mission," says NASA. The technology could be used to power a return trip to Mars without refuelling, and use recycled space junk for the fuel. Ion thrusters will be used in the European Space Agency's (ESA) mission to Mercury. The BepiColombo will launch in 2017, fly by Venus in 2019 and 2020, and be captured by Mercury's gravity in 2024.

EPS is expected to drive half of all new spacecraft by 2020. For Space-dependent sectors across the globe, the economic benefits of EP systems are said to be immense. Currently government-owned and private space players agencies are said to be scrambling to make space missions 30 per cent cheaper than now – by lowering the per-kg cost of lifting payloads to specific distances

Ion propulsion can also be used in commercial as well as military satellites. They can also provide a much more cost effective way of maneuvering satellites for orbit keeping, military surveillance and assisting Anti Satellite operations . "A more efficient on-orbit thruster capability is huge. Less fuel burn lowers the cost to get up there, plus it enhances spacecraft operational flexibility, survivability and longevity," says Major General Tom Masiello, AFRL commander.

Ion thrusters have an input power need of 1–7 kW, exhaust velocity 20–50 km/s, thrust 25–250 millinewtons and efficiency 65–80%.

Michael Patterson, senior technologist for NASA's In-Space Propulsion Technologies Program compared ion and chemical propulsion with "Tortoise and the Hare". "The hare is a chemical propulsion system and a mission where you might fire the main engine for 30 minutes or an hour and then for most of the mission you coast." "With electric propulsion, it's like the tortoise, in that you go very slow in the initial spacecraft velocity but you continuously thrust over a very long duration – many thousands of hours – and then the spacecraft ends up picking up a very large delta to velocity."

US

The NASA Glenn Research Center has been a leader in ion propulsion technology development since the late 1950s, the NASA Solar Technology Application Readiness (NSTAR) ion propulsion system enabled the Deep Space 1 mission, the first spacecraft propelled primarily by ion propulsion, to travel over 163 million miles and make flybys of the asteroid Braille and the comet Borelly.

NASA is involved in work on two different ion thrusters: the NASA Evolutionary Xenon Thruster (NEXT) and the Annular Engine. NEXT, a high-power ion propulsion system designed to reduce mission cost and trip time, operates at 3 times the power level of NSTAR and was tested continuously for 51,000 hours (equivalent to almost 6 years of operation) in ground tests without failure, to demonstrate that the thruster could operate for the required duration of a range of missions. NASA Glenn recently awarded a contract to Aerojet Rocketdyne to fabricate two NEXT flight systems (thrusters and power processors) for use on a future NASA science mission. In addition to flying the NEXT system on NASA science missions, NASA plans to take the NEXT technology to higher power and thrust-to-power so that it can be used for a broad range of commercial, NASA, and defense applications.

NASA Glenn's patented Annular Engine has the potential to exceed the performance capabilities of the NEXT ion propulsion system and other electric propulsion thruster designs. It uses a new thruster design that yields a total (annular) beam area that is 2 times greater than that of NEXT. Thrusters based on the Annular Engine could achieve very high power and thrust levels, allowing ion thrusters to be used in ways that they have never been used before. The objectives are to reduce system cost, reduce system complexity, and enhance performance (higher thrust-to-power capability).

The US Air Force's most public secret, the X-37B unmanned spaceplane, in its latest mission has carried Hall thruster as part of an experiment to improve the design for use on Advanced Extremely High Frequency (AEHF) military communications spacecraft. Once in operation, the experiment will use telemetry to record thruster performance and the thrust it puts on the spacecraft. The Air Force says that the results will be used to improve thruster and environmental models, and to better extrapolate ground test results to actual on-orbit performance. The Hall thruster experiment is a partnership between the Air Force Research Laboratory (AFRL), Space and Missile Systems Center (SMC), and Rapid Capabilities Office (CRO) and is based on the thrusters used on the first three AEHF satellites.

NexGen Ion Propulsion System in the Works by ArianeGroup and Boeing

Boeing has signed an agreement with the Orbital Propulsion unit of ArianeGroup (based in Lampoldshausen, Germany) regarding joint development of a new generation of ion propulsion systems for satellites. The system will be based on

ArianeGroup’s dual mode Radiofrequency Ion Thruster (RIT) technology, which offers a high-thrust mode for orbital transfer manœuvres.

Thanks to its high-thrust mode for orbit-raising operations, the RIT thruster system will enable Boeing to increase payload mass while reducing time-to-orbit on its satellites. Boeing is using its experience in on-orbit electric propulsion operations to update its satellite architectures for integration of the advanced RIT propulsion system.
The RIT 2X subsystem comprises the thruster itself, a high-power processing unit and a radio frequency generator. The subsystem successfully passed its preliminary design review milestone in mid-2016 and is moving towards a critical design review.

NASA to fly ion thruster on Mars orbiter

NASA Engineers want to add ion engines to the orbiter and fly the efficient electrically-powered thruster system to Mars for the first time, “The Mars mission model based on the asteroid retrieval mission would have enough power from its ion engines to launch to the red planet and return to Earth, and still fit in the envelope of a Falcon 9 or low-end Atlas 5 rocket, according to NASA official.

A Mars orbiter launching in 2022 is a prime candidate to test out new technologies – like ion drive engines, better solar arrays, and lightning-fast broadband communications between Earth and Mars – to help scientists return samples from the Martian surface, and eventually send humans there, according to Charles Whetsel, who oversees formulation of future Mars missions at NASA’s Jet Propulsion Laboratory in Pasadena, California.

ISRO first Electric Propulsion Satellite

India has launched a 2,195-kg, GSAT-9 or the South Asia Satellite om May 5 carrying an electric propulsion or EP system, the first on an Indian spacecraft. Dr. Annadurai told The Hindu that GSAT-9's EPS would be used to keep its functions going when it reaches its final slot – which is roughly about two weeks after launch – and throughout its lifetime. The new feature that will eventually make advanced Indian spacecraft far lighter. It will even lower the cost of launches tangibly in the near future.

M.Annadurai, Director of the ISRO Satellite Centre, Bengaluru, explained its immediate and potential benefits: the satellite will be flying with around 80 kg of chemical fuel – or just about 25% of what it would have otherwise carried. Managing it for more than a decade in orbit will become cost efficient.

Dr. Annadurai said, "In this mission, we are trying EPS in a small way as a technology demonstrator. Now we have put a xenon-based EP primarily for in-orbit functions of the spacecraft. In the long run, it will be very efficient in correcting the [initial] transfer orbit after launch."

"Using electric propulsion, we can send a four-tonne satellite, which is equivalent to a six-tonne satellite. Instead of chemical fuel, we save on weight and pack it with more transponders," said A S Kiran Kumar, chairman of Isro. "With electric propulsion, we can add more transponders into space on our own."

International Space Station to trial Aussie-designed thrusters that could power journey to Mars

Dr Paddy Neumann of Neumann Space and two professors have developed an ion thruster that is heading to the

International Space Station (ISS) for a year-long experiment that ultimately could revolutionise space travel.

Professor Marcela Bilek, one of the co-inventors, said they built a system in the early 2000s that was a "cathodic arc pulsed with a centre trigger and high ionisation flux". Professor Bilek explained a cathodic arc was a system that used solid fuels – metals – and worked similar to a welding arc. "Where you're ablating the material from the solid and turning it into what's called a plasma – the sort of stuff you see in the sun," she said.

Professor Bilek said magnesium came out on top in their tests as the fuel with the highest specific impulse, and so the most fuel efficient. "Magnesium happens to be a light metal, which is very abundant in aerospace materials," she said.

Australian student smashes NASA's fuel efficiency record

University of Sydney doctoral candidate in Physics, Paddy Neumann, has developed a "new kind of ion space drive" that outperforms NASA's in fuel efficiency and that can use a variety of metals, even those found in space junk, according to student newspaper Honi Soit.

NASA's current record holder for fuel efficiency is its High Power Electric Propulsion, or HiPEP, system, which allows 9,600 (+/- 200) seconds of specific impulse. However, the new drive developed by Paddy Neumann, has achieved up to 14,690 (+/- 2,000), according to student newspaper Honi Soit.

"NASA's HiPEP runs on Xenon gas, while the Neumann Drive can be powered on a number of different metals, the most efficient tested so far being magnesium," the paper explains. "As it runs on metals commonly found in space junk, it could potentially be fuelled by recycling exhausted satellites, repurposing them into fresh fuel.”

China creates New records in Power and efficiency of Ion thrusters

China has finished building the world’s most powerful ion thruster and will soon use it to improve the mobility and lifespan of its space assets, according to a state media report. Researchers at the 502 research institute, which operates under the China Aerospace Science and Technology Corp. in Beijing, have delivered a new-generation Hall-effect thruster unit to Chinese customers in the space industry, the report by the Science and Technology Daily stated.

The machine will outperform all of the ion thrusters used on satellites or spacecraft that are currently in use, it added. The daily is run by the Ministry of Science and Technology.

The most powerful ones in operation today can accelerate to 30 kilometres per second at their maximum thrust. But Mao Wei, chief designer of China’s Hall thruster, told the daily that the latest version will beat the current performance record of this kind of thruster by as much as 30 per cent. Gao Jun, another researcher involved in the project, said other countries were busy developing similar ion thrusters but that none had completed ground testing yet. As such, China should become “the first [country] to test the new technology on a high-altitude satellite,” he was quoted as saying by the newspaper.

Russia plan to use a nuclear reactor to

power an electric ion propulsion system

Hall thrusters were developed by the Soviets in the 1950’s and first deployed in 1971 on a Russian weather satellite. Over 240 have flawlessly flown since, often to boost satellites into orbit and keep them there.

The Russian government began the nuclear energy propulsion project back in 2010, providing over $17 million dollars as an initial investment. Anatoli Perminov, the former head of Russian space agency Roscosmos, told Interfax that “while the engine is expected to be fully assembled by 2017 the accompanying craft will not be ready before 2025.”

Nuclear energy can be used in two ways in powering propulsion systems: either its energy can be used to generate heat that is turned into energy or it may provide power directly. Russia is targeting this latter technology for development. They plan to use a nuclear reactor to power an electric ion propulsion system.

If Russia is able to harness nuclear energy to power long duration space missions by 2025, it would give them a significant lead in the modern space race. “Nuclear energy has significant advantages for deep space missions, in which the ability to carry fuel is a limiting factor in determining a mission’s duration. Solar power can be used for extended missions within the inner Solar System, but outer system missions are too far from the Sun to make this a practical energy source,” writes Ines Hernandez

Europe

European research into radio-frequency Ion propulsion was initially conducted in the 1960’s by the University of Giessen, Germany. Since 1970, the Lampoldshausen team has continued with the research, development and refinement of

Radio-Frequency Ion Thruster technologies, associated propulsion systems, analytical tools and techniques, processes and materials technologies.

Lampoldshausen’s first Radio-frequency Ion Thruster Assembly (RITA) was successfully demonstrated in space aboard ESA’s European Retrievable Carrier EURECA, launched by the Space Shuttle Atlantis in 1992. At that time, the RIT-10 system aboard EURECA provided a nominal specific impulse of 3,058 seconds.

QinetiQ delivers Ion Thrusters to European Space Agency

QinetiQ has delivered four electric propulsion thrusters to the European Space Agency (ESA), to be used on the BepiColombo mission to Mercury. Due for launch in 2017, the mission will be a European ‘first’, using a multiple ion engine propulsion module for interplanetary transfer.

To reach Mercury requires an extremely high velocity change, which can be achieved by ion thrusters with modest propellant quantities, compared to traditional chemical thrusters. The engines are based on the T6 ion thruster model, a development from the smaller T5 used by ESA on the successful GOCE mission. These thrusters are more effective for the BepiColombo mission than the alternative Hall and chemical technologies.

How Does an Ion Thruster Work?

As NASA explain: “An ion thruster ionizes propellant by adding or removing electrons to produce ions. Most thrusters ionize propellant by electron bombardment: a high-energy electron (negative charge) collides with a propellant atom (neutral charge), releasing electrons from the propellant atom and resulting in a positively charged ion. ” The gas produced consists of positive ions and negative electrons in proportions that result in no over-all electric charge. This is called a plasma. Plasma has some of the properties of a gas, but it is affected by electric and magnetic fields. Common examples are lightning and the substance inside fluorescent light bulbs.

The most common propellant used in ion propulsion is xenon, which is easily ionized and has a high atomic mass, thus generating a desirable level of thrust when ions are accelerated. It also is inert and has a high storage density; therefore, it is well suited for storing on spacecraft. In most ion thrusters, electrons are generated with the discharge hollow cathode by a process called thermionic emission.

Electrons produced by the discharge cathode are attracted to the discharge chamber walls, which are charged to a high positive potential by the voltage applied by the thruster’s discharge power supply. Neutral propellant is injected into the discharge chamber, where the electrons bombard the propellant to produce positively charged ions and release more electrons. High-strength magnets prevent electrons from freely reaching the discharge channel walls. This lengthens the time that electrons reside in the discharge chamber and increases the probability of an ionizing event.

The positively charged ions migrate toward grids that contain thousands of very precisely aligned holes (apertures) at the aft end of the ion thruster. The first grid is the positively charged electrode (screen grid). A very high positive voltage is applied to the screen grid, but it is configured to force the discharge plasma to reside at a high voltage. As ions pass between the grids, they are accelerated toward a negatively charged electrode (the accelerator grid) to very high speeds (up to 90,000 mph).

“The positively charged ions are accelerated out of the thruster as an ion beam, which produces thrust. The neutralizer, another hollow cathode, expels an equal amount of electrons to make the total charge of the exhaust beam neutral. Without a neutralizer, the spacecraft would build up a negative charge and eventually ions would be drawn back to the spacecraft, reducing thrust and causing spacecraft erosion.”

The primary parts of an ion propulsion system are the ion thruster, power processing unit (PPU),propellant management system (PMS), and digital control and interface unit (DCIU). The PPU converts the electrical power from a power source—usually solar cells or a nuclear heat source—into the voltages needed for the hollow cathodes to operate, to bias the grids,and to provide the currents needed to produce the ion beam. The PMS may be divided into a high-pressure assembly (HPA) that reduces the xenon pressure from the higher storage pressures in the tank to a level that is then metered with accuracy for the ion thruster components by a low-pressure assembly (LPA). The DCIU controls and monitors system performance,and performs communication functions with the spacecraft computer.

Advantages

These thrusters have high specific impulses—ratio of thrust to the rate of propellant consumption, so they require significantly less propellant for a given mission than would be needed with chemical propulsion,” says NASA. These can be more than 10 times as fuel efficient as other rocket engines.

Another attraction of using this kind of thruster is that it does not need the kind of high temperatures required by forms of chemical propulsion. This kind of electric propulsion system is also lighter in weight, meaning that future space trips could be more feasible.

The advantages include : Highest specific impulse offers substantial mass saving (>3000s); High performance at low complexity; Reduced power processing unit mass; Narrow beam divergence; Robust design concept with a large domain of operational stability; Large throttle range and adaptable to available electric power; Excellent thrust stability and fast thrust response and Highest growth potential with increasing electric power in near and medium-term future

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