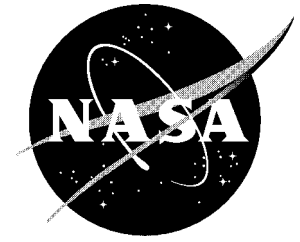


NASA Facts

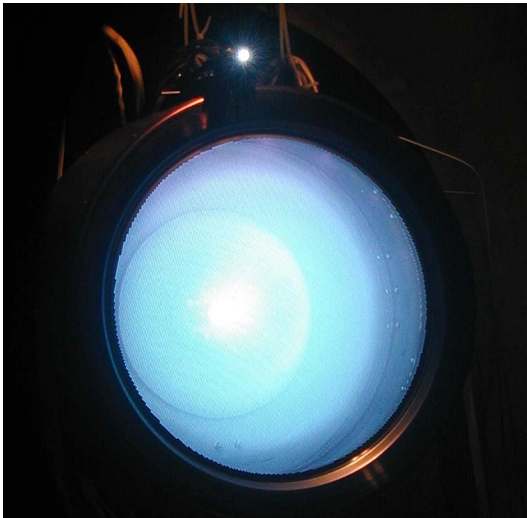


National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135-3191

FS-2004-11-021-GRC

Ion Propulsion



NASA Evolutionary Xenon Thruster (NEXT) ion thruster in operation.

Introduction

The propulsion of choice for science fiction writers has become the propulsion of choice for scientists and engineers at NASA. The ion propulsion system's efficient use of fuel and electrical power enable modern spacecraft to travel farther, faster, and cheaper than any other propulsion technology currently available. Ion thrusters are currently used for stationkeeping on communication satellites and for main propulsion on deep space probes. Ion thrusters expel ions to create thrust and can provide higher spacecraft top speeds than any other rocket currently available.

What Is an Ion?

An *ion* is simply an atom or molecule that is electrically charged. *Ionization* is the process of electrically charging an atom or molecule by adding or removing electrons. Ions can be positive (when they lose one or more electrons) or negative (when they gain one or more electrons). A gas is considered ionized when some or all the atoms or molecules contained in it are converted into ions.

Plasma is an electrically neutral gas in which all positive and negative charges—from neutral atoms, negatively charged electrons, and positively charged ions—add up to zero. Plasma exists everywhere in nature; it is designated as the fourth state of matter (the others are solid, liquid, and gas). It has some of the properties of a gas but is affected by electric and magnetic fields and is a good conductor of electricity. Plasma is the building block for all types of electric propulsion, where electric and/or magnetic fields are used to push on the electrically charged ions and electrons to provide thrust. Examples of plasmas seen every day are lightning and fluorescent light bulbs.

The conventional method for ionizing the propellant atoms in an ion thruster is called *electron bombardment*. The majority of NASA's research consists of electron bombardment ion thrusters. When a high-energy electron (negative charge) collides with a propellant atom (neutral charge), a second electron is released, yielding two negative electrons and one positive ion.

An alternative method of ionization called *electron cyclotron resonance* (ECR) is also being researched at NASA. This method uses high-frequency radiation (usually microwaves), coupled with a high magnetic field to heat the electrons in the propellant atoms, causing them to break free of the propellant atoms, creating plasma. Ions can then be extracted from this plasma.

Ion Thruster Operation

Modern ion thrusters use inert gases for propellant. The majority of thrusters use xenon, which is chemically inert, colorless, odorless, and tasteless. The propellant is injected from the downstream end of the thruster and flows toward the upstream end. This injection method is preferred because it increases the time that the propellant remains in the chamber.

In a conventional ion thruster, electrons are generated by a hollow cathode, called the discharge cathode, located at the center of the engine on the upstream end. The

electrons flow out of the discharge cathode and are attracted to the discharge chamber walls, which are charged to a high positive potential by the thruster's power supply.

The electrons from the discharge cathode ionize the propellant by means of electron bombardment. High-strength magnets are placed along the discharge chamber walls so that as electrons approach the walls, they are redirected into the discharge chamber by the magnetic fields. By maximizing the length of time that electrons and propellant atoms remain in the discharge chamber, the chance of ionization is maximized, which makes the ionization process as efficient as possible.

In an ion thruster, ions are accelerated by electrostatic forces. The electric fields used for acceleration are generated by electrodes positioned at the downstream end of the thruster. Each set of electrodes, called *ion optics* or *grids*, contains thousands of coaxial apertures. Each set of apertures acts as a lens that electrically focuses ions through the optics. NASA's ion thrusters use a two-electrode system, where the upstream electrode (called the *screen grid*) is charged highly positive, and the downstream electrode (called the *accelerator grid*) is charged highly negative. Since the ions are generated in a region of high positive and the accelerator grid's potential is negative, the ions are attracted toward the accelerator grid and are focused out of the discharge chamber through the apertures, creating thousands of ion jets. The stream of all the ion jets together is called the ion beam. The thrust force is the force that exists between the upstream ions and the accelerator grid. The exhaust velocity of the ions in the beam is based on the voltage applied to the optics. While a chemical rocket's top speed is limited by the thermal capability of the rocket nozzle, the ion thruster's top speed is limited by the voltage that is applied to the ion optics (which is theoretically unlimited).

Because the ion thruster expels a large amount of positive ions, an equal amount of negative charge must be expelled to keep the total charge of the exhaust beam neutral. A second hollow cathode called the *neutralizer* is located on the downstream perimeter of the thruster and expels the needed electrons.

The Electric Propulsion System

The ion propulsion system (IPS) consists of five main parts: the power source, power processing unit (PPU), propellant management system (PMS), the control computer, and the ion thruster. The IPS power source can be any source of electrical power, but solar and nuclear

are the primary options. A solar electric propulsion system (SEP) uses sunlight and solar cells for power generation. A nuclear electric propulsion system (NEP) uses a nuclear heat source coupled to an electric generator. The PPU converts the electrical power generated by the power source into the power required for each component of the ion thruster. It generates the voltages required by the ion optics and discharge chamber and the high currents required for the hollow cathodes. The PMS controls the propellant flow from the propellant tank to the thruster and hollow cathodes. Modern PMS units have evolved to a level of sophisticated design that no longer requires moving parts. The control computer controls and monitors system performance. The ion thruster then processes the propellant and power to perform work.

Modern ion thrusters are capable of propelling a spacecraft up to 90,000 meters per second (over 200,000 miles per hour (mph)). To put that into perspective, the space shuttle is capable of a top speed of around 18,000 mph. The tradeoff for this high top speed is low thrust (or low acceleration). Thrust is the force that the thruster applies to the spacecraft. Modern ion thrusters can deliver up to 0.5 Newtons (0.1 pounds) of thrust, which is equivalent to the force you would feel by holding nine U.S. quarters in your hand. To compensate for low thrust, the ion thruster must be operated for a long time for the spacecraft to reach its top speed. Ion thrusters use inert gas for propellant, eliminating the risk of explosions associated with chemical propulsion. The usual propellant is xenon, but other gases such as krypton and argon may be used.

Past

The NASA Glenn Research Center has been the lead for electric propulsion since work on ion propulsion began there in the 1950s. The first operational test of an ion propulsion system in space was the Space Electric Rocket Test 1 (SERT 1), which flew on July 20, 1964, and successfully completed its goal of 31 minutes of operation before its return to Earth. Many successful tests of ion propulsion followed. The Ion Auxiliary Propulsion System (IAPS) project from 1974 to 1983 developed an 8-centimeter mercury IPS for satellite stationkeeping. The NASA Solar Technology Application Readiness (NSTAR) project developed a 30-centimeter IPS that was used as the main propulsion on the Deep Space 1 (DS1) spacecraft from 1998 to 2001. DS1 was the first use of electric propulsion for spacecraft main propulsion. The NSTAR thruster on DS1 propelled the spacecraft 263,179,600 kilometers (163,532,236 miles) at speeds up to 4,500 meters per second (10,066 mph). Over the entire mission, the NSTAR thruster demonstrated 200 starts and 16,246 hours of operation.

Present

NASA's Energetics program at Glenn develops the core technologies that enable major enhancements in ion propulsion systems. The research encompasses strong development and test efforts, computer modeling, advancements in hollow cathode technology, and enhanced ion optics technologies, to name a few areas. By studying the basic principles involved with plasmas, models can be generated that reduce the cost to design future ion thrusters. Enhancements in component technologies produce components that can last longer or operate in extreme conditions.

The NASA Evolutionary Xenon Thruster (NEXT) project is developing a high-power SEP IPS that will reduce mission cost and trip time. NEXT is capable of performing a wide variety of missions to targets of interest such as Mars and Saturn. In 2003, a single NEXT thruster demonstrated over 2000 hours of operation at 7 kilowatts. The NEXT single string integration test, also completed in 2003, demonstrated operation of the NEXT PPU, PMS, and thruster as a complete IPS.

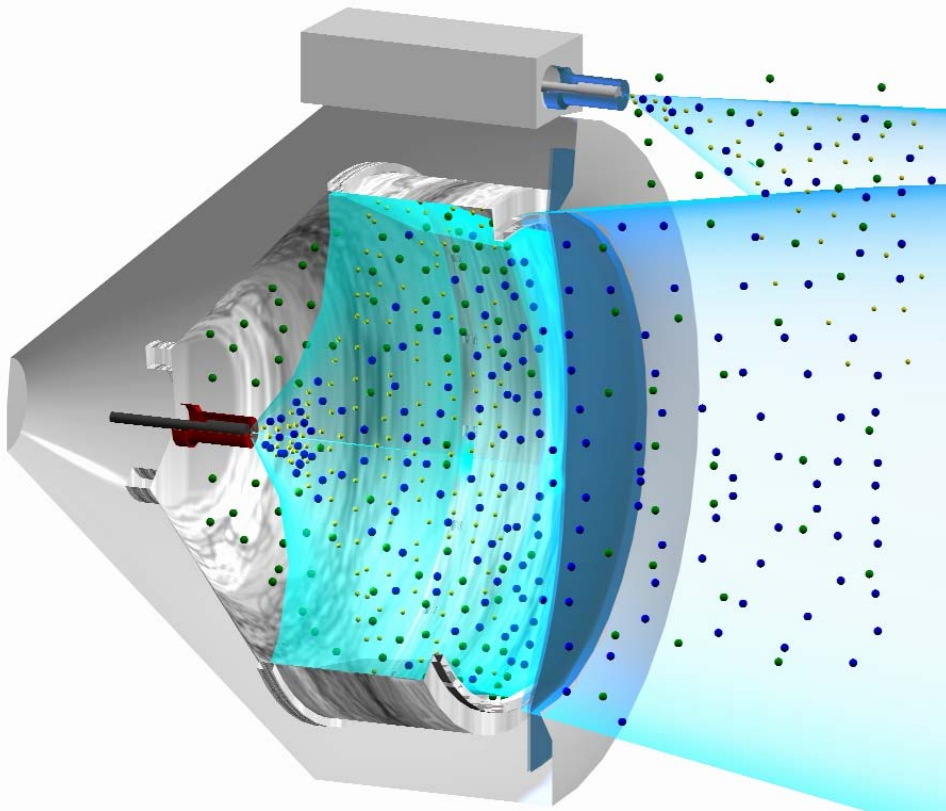
The High Power Electric Propulsion (HiPEP) project is developing a high-power NEP IPS for the Jupiter Icy Moons Orbiter (JIMO) spacecraft. The HiPEP thruster,

which is under development at Glenn, is unique in that it has the ability to operate at high power levels in both a conventional hollow cathode configuration and a microwave ECR configuration. The HiPEP ion thruster is currently the most powerful inert gas ion thruster ever built. Early tests in 2004 demonstrated power levels of 40 kilowatts and exhaust velocities in excess of 90,000 meters per second (over 200,000 mph).

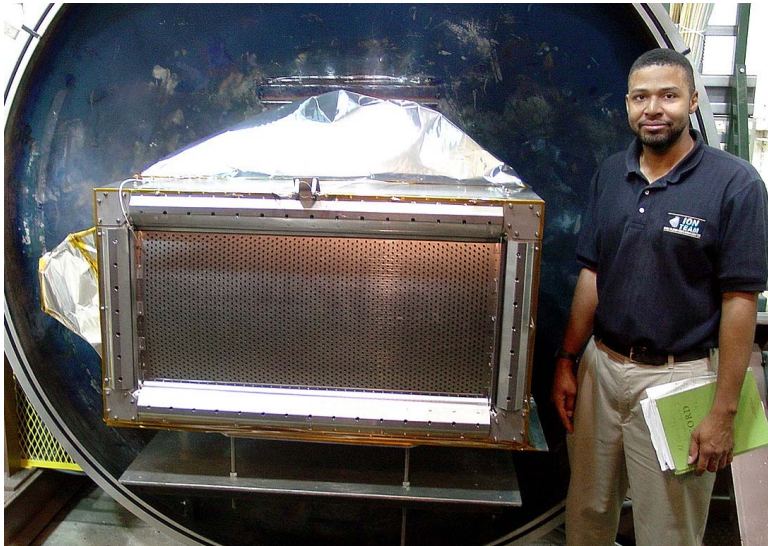
Future

More and more companies are beginning to use satellites with electric propulsion to extend the operational life of satellites and reduce launch and operation costs. This produces savings that can be passed along to consumers.

NASA's primary application of ion propulsion will be for main propulsion on long missions that are difficult or impossible to perform using other types of propulsion. The Dawn spacecraft, scheduled for launch in May 2006, will use three NSTAR ion thrusters as main propulsion. The mission will study Ceres and Vesta, two protoplanets located in the asteroid belt that exists between Mars and Jupiter. By studying these protoplanets, which were among the first bodies formed in our solar system, researchers hope to gain valuable information about the solar system's early development.



Overview of ion thruster operation.



High Power Electric Propulsion (HiPEP) ion thruster installed for testing.

Research in the area of ion propulsion continues to push the envelope of propulsion technology. Advancements are being made that allow the thrusters to operate at higher power levels, higher speeds, and for longer durations. PPU and PMS technologies are being developed that will allow NASA to build lighter and more compact systems while increasing reliability. As new power sources become available, higher power thrusters will be developed that provide greater speed and more thrust. Supporting technologies such as carbon-based ion optics and ECR discharges may greatly increase ion thruster operational life, enabling longer duration missions or high-power IPS operation. These technologies will allow human-kind to explore the farthest reaches of our solar system.

The JIMO spacecraft will use an array of high-power ion thrusters as main propulsion. JIMO will perform an extensive exploration of Jupiter's icy moons Callisto, Ganymede, and Europa. The spacecraft will investigate each moon's composition, history, and potential for sustaining life.

For more information

visit the GRC Ion Propulsion Web site at
<http://www.grc.nasa.gov/www/ion>

or contact

Michael Patterson

NASA Glenn Research Center

Cleveland, Ohio 44135

E-mail: Michael.J.Patterson@grc.nasa.gov

or

Information and Publications Office

NASA Glenn Research Center

Cleveland, Ohio 44135

216-433-5573