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Glenn Research Center
Cleveland, Ohio 44135–3191

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Innovative Engines

Glenn Ion Propulsion Research Tames the Challenges of 21st Century Space Travel

Ion propulsion, a futuristic technology that for decades catapulted spacecraft through the pages of science fiction novels is now a reality. A Glenn-designed ion engine, just 12 inches (30 centimeters) in diameter, is the main propulsion source for Deep Space 1—a 20th Century spacecraft now off on its primary mission to validate technologies for 21st century spacecraft.

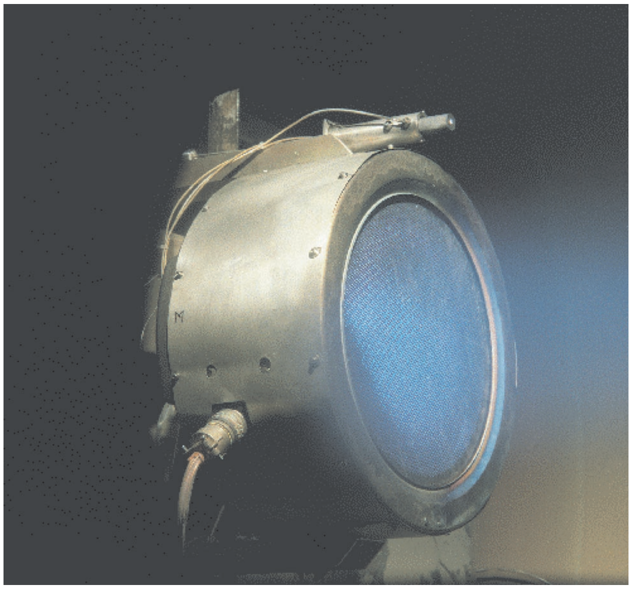
An ion propulsion system converts power from the spacecraft power system into the kinetic energy of an ionized gas jet. That jet, as it exits the spacecraft, propels it in the opposite direction. The system, or any electric propulsion system, consists of just four major components: a computer for controlling and monitoring system performance; a power source (on Deep Space 1 (DS1) this source is the solar concentrator arrays) a power processing unit for converting power from the solar arrays to the correct voltages for the engine; and the thruster, or engine itself.

Ion Engine Operation

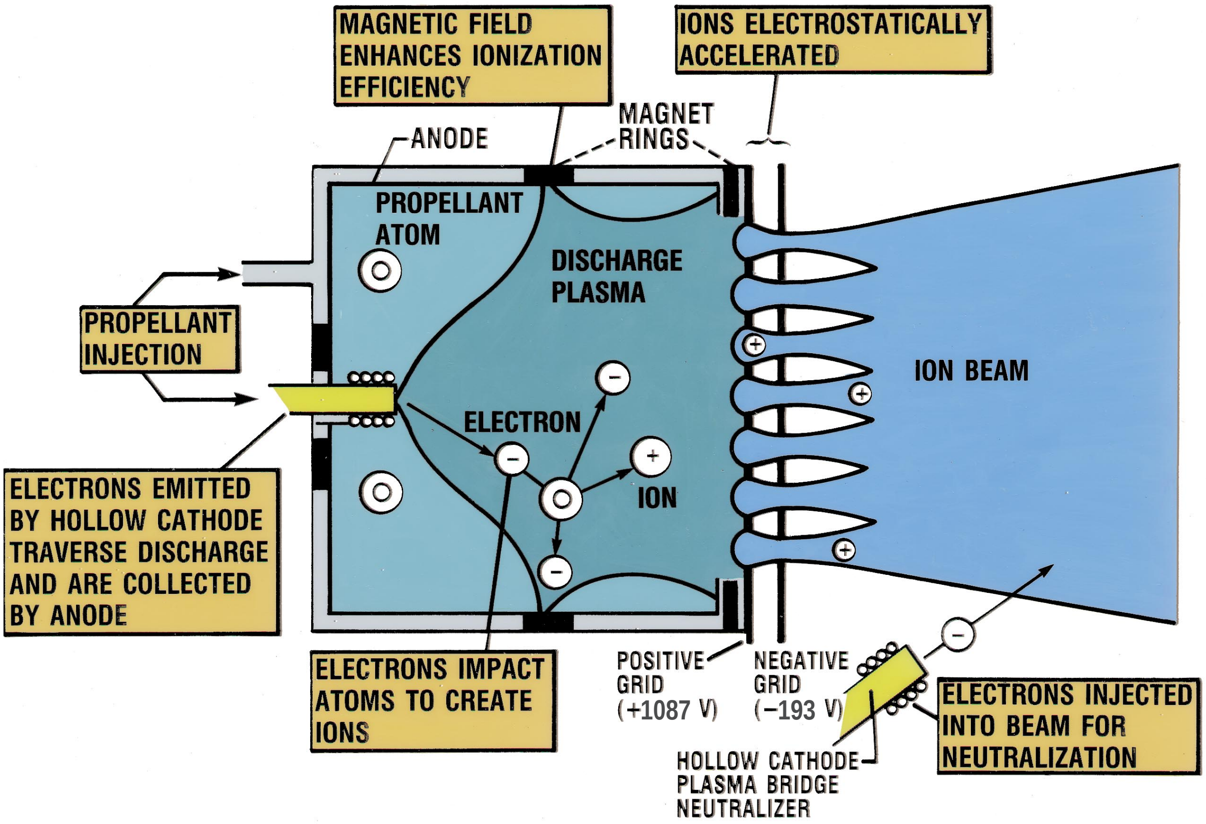
The fuel used in DS1’s ion engine is xenon, a chemically inert, colorless, odorless, and tasteless gas. The xenon fuel fills a chamber ringed with magnets. When the ion engine is running, electrons emitted from a cathode strike atoms of xenon, knocking away one of the electrons orbiting an atom’s nucleus and making it into an ion. The magnets’ magnetic field controls the flow of electrons and, by increasing the electrons’ residence time in the chamber, increases the efficiency of the ionization.

At the rear of the chamber is a pair of metal grids that are charged with 1280 volts of electric potential. The force of this electric field exerts a strong “electrostatic” pull on the xenon ions—much like the way that bits of lint are pulled to a pocket comb that has been given a static electric charge by rubbing it on wool. The xenon ions shoot past the grids at speeds of more than 88,000 miles per hour (146,000 kilometers per hour), continuing right on out the back of the engine and into space. These exiting ions produce the thrust that propels the spacecraft. A second electron-emitting cathode, downstream of the grids, neutralizes the positive charge of the ion beam to keep the spacecraft neutral with respect to its environment.

At full throttle, the ion engine consumes about 2300 watts of electrical power and puts out 0.02 pound (90 millinewtons) of thrust. This is comparable to the force exerted by a single sheet of paper resting on the



The ion engine prototype showing the faint blue glow of charged atoms being emitted.



Overall design of an ion engine.

palm of a hand. Typical chemical on-board propulsion systems, on the other hand, produce far greater thrust—100 to 500 pounds (450 to 2250 newtons)—but for far shorter times. A chemically propelled spacecraft gets its big boost and then coasts at constant speed until the next boost. But an ion engine can produce its small thrust continually and thereby provide near constant acceleration and, so, shorter travel times.

Ion propulsion is also 10 times more efficient than chemical on-board propulsion systems. This greater efficiency means less propellant is needed for a mission. In turn, the spacecraft can be smaller and lighter, and the launch costs lower.

Deep Space 1 carries 178 pounds (81 kilograms) of xenon propellant, which is capable of fueling engine operation at one-half throttle for over 20 months. Ion propulsion will increase the speed of DS1 by 7900 miles per hour (12,700 kilometers per hour) over the course of the mission.

Early Work at Glenn

Electric propulsion technology, which includes ion engines, has been studied at Glenn (at that time the NASA Lewis Research Center) since the 1950's. Ion propulsion technology development at Glenn began when Dr. Harold Kaufman, now retired from NASA, designed and built the first broad-beam electron-bombardment ion engine in 1959. It used mercury as fuel, but is otherwise similar to the engine flying today on DS1. The laboratory tests of variations of the original ion engine were promising enough for Glenn to begin suborbital flight tests in the early 1960's. By 1964, an ion engine launched on the Space Electric Rocket Test I (SERT I) operated for all of its planned 31 minutes before returning to Earth.

In 1970, two modified ion engines were launched on SERT II; one operated for nearly three months and the other for more than five. Both engines suffered grid shorts, believed to have been be caused by debris from thruster grid wear, before the planned end of the mission. After an attitude control maneuver cleared its grid of the short in 1974, one of the engines was started and was operated on and off for six more years.

The information learned from these genuine space success stories was used to refine and improve the technology that today flies on communications satellites and, of course, on DS1.

Lessons Learned

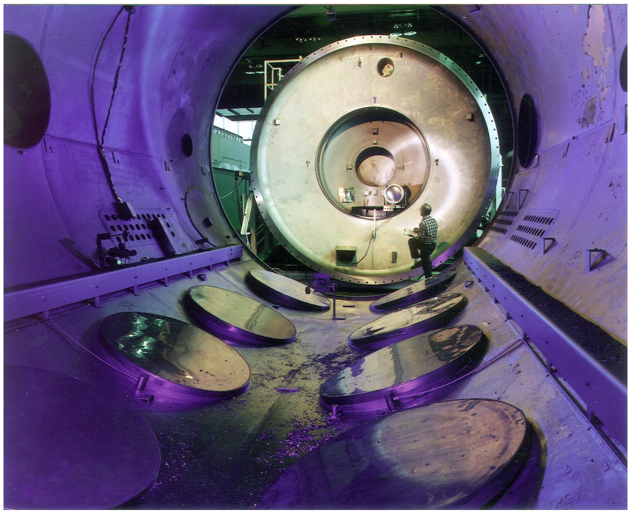
Early ion engines used mercury or cesium instead of xenon as propellants. But both proved to be difficult to work with. At room temperature, mercury is a liquid and cesium is a solid, making them easy to store. But both had to be heated to turn them into gases. Then there was the cleanup. After exiting the ion engine, some mercury or cesium atoms would condense onto the ground test hardware, causing numerous cleanup difficulties. In the 1970's NASA managers decided that if ion propulsion research was to continue, it would have to be environmentally clean and less hazardous. Glenn researchers soon turned to xenon as a cleaner, simpler fuel for ion engines, with many of the same characteristics as mercury. (Glenn researchers had worked on cesium ion engines in the mid 1950's.)

One of the first xenon ion-engine-like devices ever flown was a Hughes Research Laboratories design launched in 1979 on the Air Force Geophysics Laboratory's Spacecraft Charging at High Altitude (SCATHA) satellite. It was used, not to propel the spacecraft, but to change its electrical charge. Researchers then studied the effects of the "charging" on spacecraft system performance. In 1997, Hughes launched the first commercial use of a xenon ion engine on the communications satellite PanAmSat 5. This ion engine is used for stationkeeping, that is, keeping the satellite in its proper orbit and orientation with respect to Earth.

The NTSAR Program

In the early 1990s, NASA identified improved electric propulsion as an enabling technology for future deep space missions. Glenn engineers believed that their ion engine technology was the closest to being ready for long, complex missions. NASA Glenn partnered with the Jet Propulsion Laboratory (JPL) in the NASA Solar Electric Power Technology Application Readiness (NSTAR) project. The purpose of NSTAR was to develop a xenon-fueled ion propulsion system for deep space missions. Glenn developed the engines and power processors, and JPL was responsible for the development of the xenon feed system, the diagnostics, and integration of the hardware into the spacecraft.

In 1996, the prototype engine built at Glenn endured 8000 hours of operation in a JPL vacuum chamber that simulates conditions of outer space. The results of the prototyping were used to define the design of flight hardware that was built for DS1 by Hughes Electron Dynamics Division and Spectrum Astro Inc.



Ground test setup in the Glenn Research Center's Electric Propulsion Laboratory.

One of the challenges was developing the compact, lightweight power processing unit that converts power from the solar arrays into the voltages needed by the engine. NSTAR team contractor, Hughes designed a 2500-watt power processor that weighs a little over 33 pounds (15 kilograms) and has an efficiency of 93 percent.

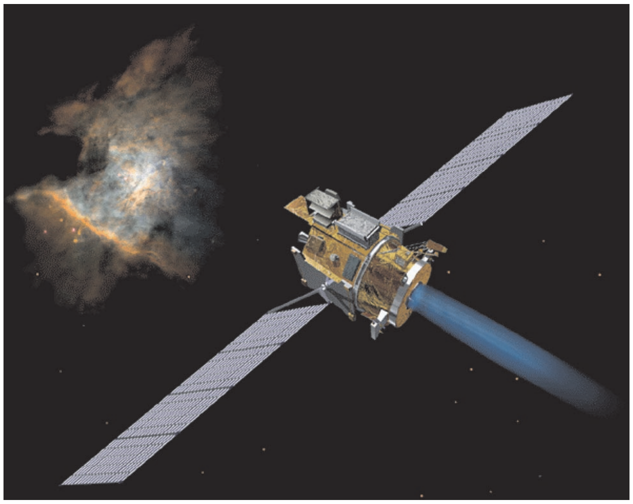
Deep Space 1

The first spacecraft in NASA's New Millennium Program of missions to flight-test new technologies, DS1 blasted into space in October 1998 aboard a Delta II launch vehicle. Now on its own and headed toward a flyby of asteroid 1992 KD, 12 new technologies aboard the spacecraft are being tested for use on future space science missions. Among those 12 is DS1's main propulsion source, the Glenn-designed NSTAR ion engine.

The following December the spacecraft was 26 times farther away from Earth than the moon. The ion engine had surpassed it performance goals by twice thrusting continuously for over 330 hours, the longest continuous thrusting of any other deep space propulsion system.

The Future

The next New Millennium Program mission to use Glenn ion engine technology will be Deep Space 4/Champollion, which will rendezvous (match orbits) with the periodic Comet Tempel 1. Three NSTAR ion engines (with minor modifications) will provide the primary propulsion for the spacecraft. The planned launch date is in 2003.



Artists conception of Deep Space 1 in flight.

Glenn engineers are also responding to and anticipating mission planners' needs by developing both higher and lower power ion propulsion systems.

Ion engines with extended performance and higher power NSTAR engines, in the 5-kilowatt and 0.04-pound-thrust range, are candidates for propelling spacecraft to Europa, Pluto, and other small bodies in deep space. But only if the cost saving from using smaller, less expensive launch vehicles, shorter trip times and, thus, lower mission operations costs can be demonstrated. Glenn engineers plan to achieve higher ion engine power levels by retrofitting NSTAR engine with enhanced components.

Low power (100 to 500 watts) systems can be used to deliver miniaturized robot spacecraft (launched using small, inexpensive rockets) to interesting space bodies including comets, asteroids, and planets. Such missions will allow for the delivery of instruments, sensors, and mobile vehicles to the bodies. Laboratory tests on low-power, light-weight ion propulsion system components and subsystems are now underway at Glenn.

For more information, visit Glenn Deep Space 1 web site at:
http://www.grc.nasa.gov/WWW/PAO/ds1.htm

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Information and Publications Office
MS 8-1
NASA Glenn Research Center
Cleveland, Ohio 44135
(216) 433-5573