PPPL digest
PRINCETON PLASMA PHYSICS LABORATORY
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Hall Thruster Experiment Underway at PPPL

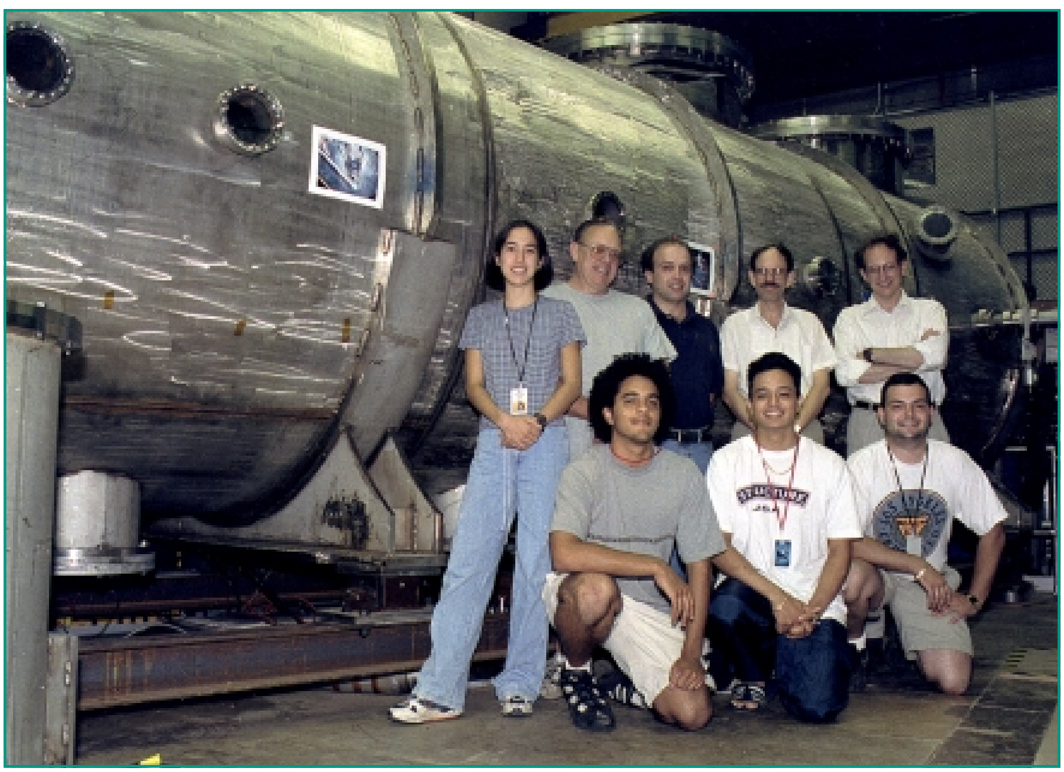
The Hall Thruster is a plasma-based propulsion system for space vehicles. The amount of fuel that must be carried by a satellite depends on the speed with which the thruster can eject it. Chemical rockets have very limited fuel exhaust speed. Plasmas can be ejected at much higher speeds, therefore less fuel need be carried on board.

During the past twenty years, the Russians placed in orbit about 100 Hall Thrusters. However, the vast majority of satellites worldwide have relied on chemical thrusters and, to a lesser extent, ion thrusters.

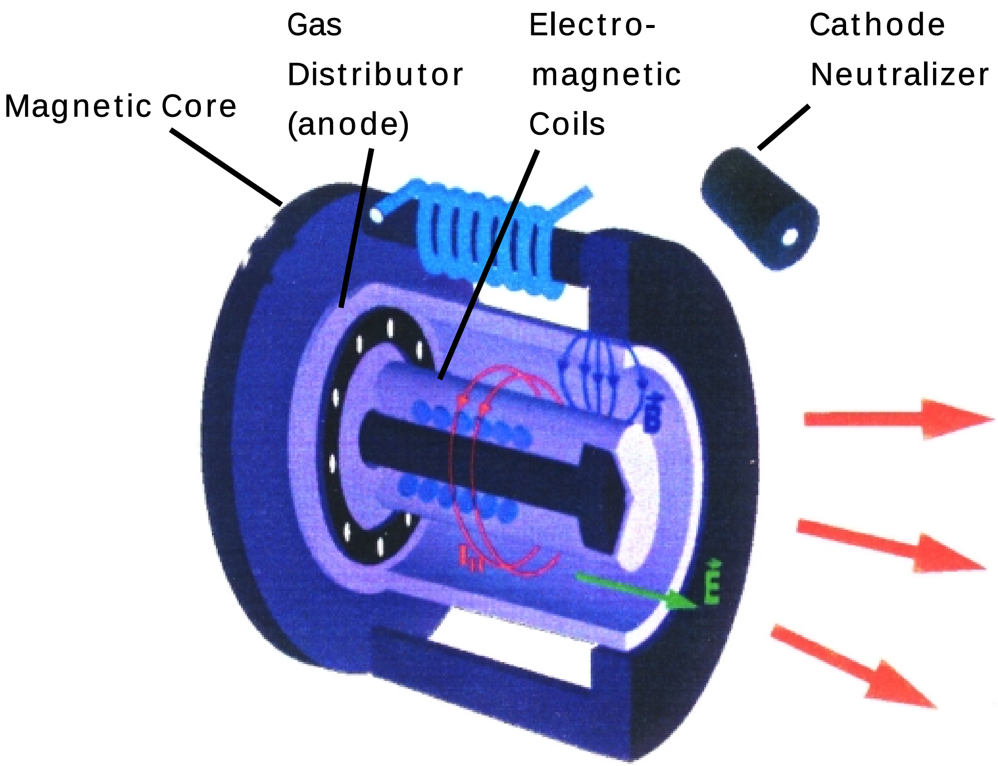
In 1999, a Hall Thruster Experiment was established at the Princeton Plasma Physics Laboratory (PPPL). The PPPL experiment is the result of a collaborative theoretical research effort with the Center for Technological Innovation at Holon, Israel. This study, funded by the U.S. Air Force Office of Scientific Research, identified improvements that might make Hall Thrusters more attractive for commercial and military applications. The U.S. Air Force Office of Scientific Research, the U.S. Department of Energy, and the Defense Advanced Research Projects Agency are funding the current work.

Hall Thruster Operation

A conventional ion thruster consists of two grids, an anode and a cathode, between which a voltage drop occurs. Positively charged ions accelerate away from the anode toward the cathode grid and through it. After the ions



The Hall Truster Team and the PPPL Hall Thruster Experiment.



The Hall Thruster concept.

get past the cathode, electrons are added to the flow, neutralizing the output to keep it moving. A thrust is exerted on the anode-cathode system, in a direction opposite to that of the flow. Unfortunately, a positive charge builds up in the space between the grids, limiting the ion flow and, therefore, the magnitude of the thrust that can be attained.

In a Hall Thruster, electrons injected into a radial magnetic field neutralize the space charge. The magnitude of the field is approximately 200 gauss, strong enough to trap the electrons by causing them to spiral around the field lines. The magnetic field and a trapped electron cloud together serve as a virtual cathode (see illustration above). The ions, too heavy to be affected by the field, continue their journey through the virtual cathode. The movement of the positive and negative electrical charges through the system results in a net force on the thruster in a direction opposite that of the ion flow.

Applications

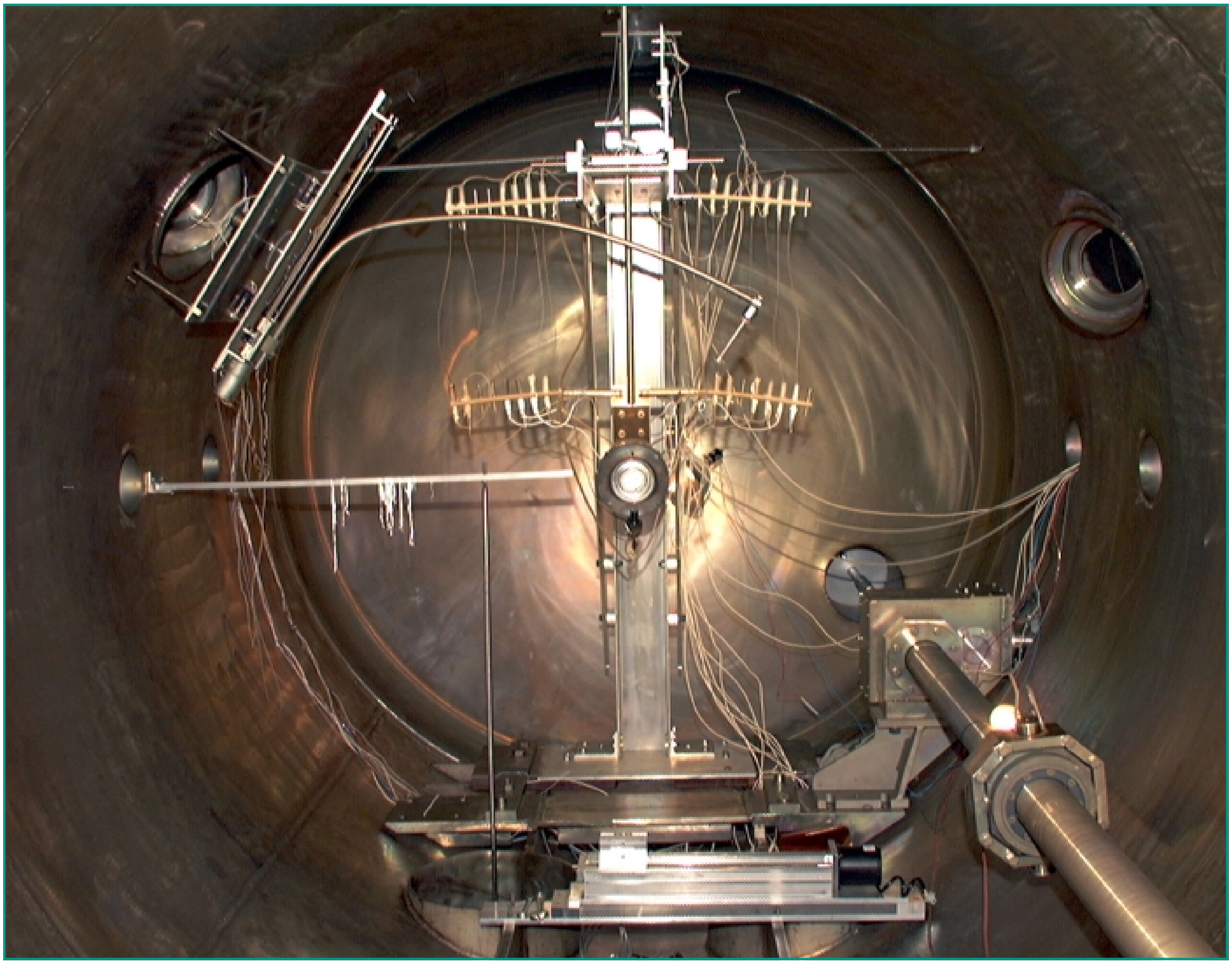
Generally, thrusters are used to compensate for atmospheric drag on satellites in low-earth orbit, to reposition satellites in geosynchronous orbit, or to raise a satellite from a lower orbit to geosynchronous orbit. As a basic rule of thumb, for each kilogram of satellite mass one or two watts of on-board power are available. PPPL's Hall Thruster consumes several hundred watts of power, making it suitable for a satellite with a mass in the range of a few hundred kilograms. PPPL physicists believe there may be a market for Hall Thrusters operating at 1,000 watts or more, but say predictions are difficult to make. They also speculate about the development of Hall microthrusters with power outputs in the 100-watt range, useful for very small satellites with masses of 50 to 100 kilograms. One could envision a large satellite disbursing hundreds of the smaller ones for the exploration of a planet or as a spaced-based radar array. The Hall Thruster may be too power hungry for this application, but answers to these and other questions may emerge from research now underway at PPPL.

Hall Thruster Propellant

Plasma thrusters for current space applications employ xenon propellant. Xenon is relatively easy to ionize and store onboard the spacecraft. It also has a high atomic number (54), which means a lot of mass per ionization energy expended. The ionization energy is an unavoidable inefficiency; in the range of exhaust velocities most useful for current space applications — about 15 km/sec — this energy loss for once-ionized xenon is less than 10 percent of the exhaust energy. (If the weight per atom were half, this percentage would double.)

Installation

The site of the former PPPL S-1 Spheromak Experiment was selected for the Hall Thruster Experiment. Fa-



Interior view of the PPPL Hall Thruster.

cility work began with the relocation of the 15-ton, 28-foot by 8-foot manipulator tank, previously constructed for use on the Tokamak Fusion Test Reactor. The vessel is now being used as the vacuum chamber for the Hall Thruster Experiment. PPPL's state-of-the-art prototype Hall Thruster was then assembled inside the vacuum chamber. A complete set of diagnostics was installed and experiments got underway. Less than $200,000 was spent to assemble the PPPL's Hall Experiment, which has capabilities comparable to installations that are considerably more expensive.

Initial Results

Initial results indicate that PPPL's Hall Thruster operating at 900 watts does so with an efficiency that is comparable to state-of-the-art thrusters. Planned upgrades include segmenting the thruster. Each segment would be held at a specific electric potential, enabling researchers to control exactly where the voltage drop occurs along the length of the thruster. PPPL's Hall Thruster was designed with a modular configuration to allow multiple thruster geometries that could be diagnosed in detail easily. This includes the ability to measure precisely in three dimensions how the thrust varies with position. This information could be used to arrive at techniques to narrow the plume and obtain more control over the outflow from the thruster, possibly improving its efficiency.

In October 1999 two significant achievements were reported for PPPL's Hall Thruster. First, in a low mass-flow-rate situation, segmented thruster operation did indeed lead to narrowing of the plume by as much as 20 degrees. Second, a new PPPL thruster, employing a cylindrical rather than the conventional annular acceleration configuration, was successfully fired with promising results. The cylindrical approach is thought to be better adapted to scale down for the microthruster application. These capabilities and advances may now allow PPPL to develop a new line of Hall Thrusters for commercial and military applications.

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