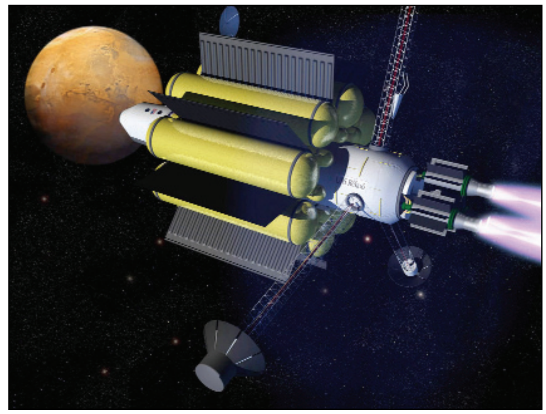
about Plasmas
from the Coalition for Plasma Science

Plasma Propulsion for Space Flight

We dream of going to the stars! As young children many of us have been awestruck by the possibility of space travel. Indeed, in the last 50 years we have witnessed the development of the first ships that could transport humans beyond Earth.



A Mars mission as it might look in the future, driven by a plasma rocket and powered by nuclear reactors.

Yet we still lack the ships required to venture far into the vastness of space. With current technology, even a visit to one of our nearest planetary neighbors, Mars, would require a very long journey, in fragile and limited spacecraft. Travelers would encounter staggering difficulties, including more than six months of debilitating weightlessness and persistent radiation. If humans were to travel to Mars today, their bodies and minds would suffer considerably during the journey.

Many of these difficulties are due to the limitations of today's chemical rockets. Even after remarkable advances in the last 50 years, the fuel consumption of those rockets is still so high that only a tiny fraction of the ship manages to reach its final destination. Witness, for example, the gargantuan external fuel tank required to bring the space shuttle to an orbit only a few hundred miles up. A trip to the Moon requires a much greater amount of fuel, and a trip to Mars would require even more.

Plasma rockets, on the other hand, open up new and exciting possibilities for fast space transportation. Utilizing ionized particles accelerated by electric and magnetic fields, these engines expand the range of rocket propulsion far beyond the limits of the chemical rocket, with a fuel consumption very much lower. Many plasma rockets have been under development for years, even decades, and some are already in limited operation.

Plasma rockets, however, are dependent upon the availability of electric power, which is still limited in space, since electricity is generated mainly by solar arrays. Because of this, plasma rockets have evolved over time as low-power devices unsuitable for long-distance transportation and human space flight.

This picture is rapidly changing. Major advances in solar technology have increased the available electrical power, opening new and exciting possibilities for high-power plasma propulsion. In addition, renewed interest in nuclear power for space missions far from the Sun is creating a new niche for high-power plasma rockets.

The basic principle of rocket propulsion stems from Newton's third law of motion, the so-called law of action and reaction. That principle applies to the motion of a garden hose as well as it does to the powerful engines of the space shuttle. A rocket propels itself by expelling material at high velocity in the opposite direction to its motion. The material is usually a gas, and heat from a chemical reaction generally imparts the velocity. The heat builds pressure in a combustion chamber and is converted to exhaust velocity by the action of a properly designed nozzle.

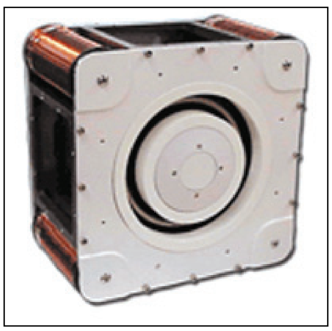
One can achieve the same thrust by either ejecting more material at low velocity or less material at high velocity. Clearly, since the material must be carried on board, the latter approach is preferred. In order to minimize the amount of material carried, one seeks to achieve the highest possible exhaust velocity. Exhaust velocities far beyond the reach of chemical rockets can be achieved by using plasma, in which atoms of the exhaust gases have been stripped of some of their electrons, making it a soup of charged particles.

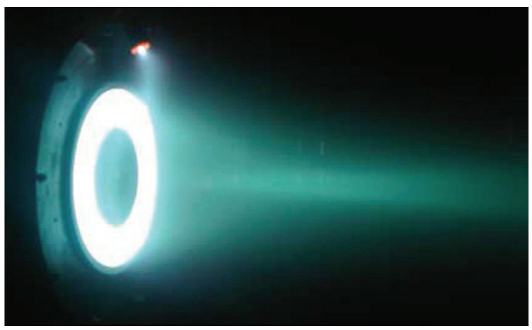
Continued on back

The temperature of a plasma generally starts at about 11,000°C, but present day laboratory plasmas can be a thousand times hotter. Particles in those hotter plasmas move at velocities exceeding 300,000 meters per second. These temperatures are comparable to those in the interior of our Sun. No known material could survive prolonged direct contact with such plasma. Fortunately, plasmas respond well to electric and magnetic fields. A magnetic channel can be constructed to both heat and guide a hot plasma so that the plasma never touches the material walls.

Power requirements increase very rapidly as the exhaust velocity increases. While solar power remains viable for robotic cargo missions in the Earth-Moon environment, for human transportation it is difficult to envision any other option than nuclear electric power. This is especially true for missions beyond Mars, where the power of the Sun is relatively low.

A number of low-power plasma rockets are already in use. The best known and oldest technology is the ion engine, which uses a metal grid to extract and accelerate ions from a relatively low temperature and low density plasma discharge. The ion jet must be neutralized by a spray of electrons ejected from a neutralizing gun at the rocket exhaust; otherwise the spacecraft would build up a negative electric charge that would ultimately pull the ions back in. Ion engines produce exhaust velocities up to 70 kilometers per second using Xenon propellant. A variation of the ion engine is the Hall Effect Thruster, which does away with the grid, replacing it with a magnetically rigidized cloud of electrons. This technique reduces the erosion and heating of rocket components that are directly exposed to plasma bombardment, a major problem in plasma rocket engineering.





Left: A Hall Effect Thruster. Right: The jet from a Hall Effect Thruster. In this type of engine, ions are ejected by an electric field inside the device.

The plasma density in ion and Hall thrusters is generally low due to physics constraints. Therefore, their power density is also low. This implies that high-power systems of those types would need to be physically large. Other systems under development, such as the Magneto Plasma Dynamic Thruster (MPD), the Variable Specific Impulse Magneto Plasma Rocket (VASIMR), and the Pulsed Inductive Thruster (PIT) can reach much higher power densities. All offer comparative advantages and disadvantages, and intensive research and development is currently underway to test and deploy them.

The low-power Hall Effect Thruster is presently being used in commercial satellites for small “station keeping” maneuvers, that is, for maintaining the satellite’s position. For primary propulsion, considerable research is being carried out on alternate high-power radio-frequency-driven systems. One such concept is VASIMR, which is being developed by the author and is depicted on page one. This engine can operate with a number of alternate gases and does not rely on rare and expensive propellants such as Xenon. In this engine, ions are guided and accelerated out the nozzle by magnetic fields.

In the future, plasma rockets could be valuable in a number of ways. For example, low-power rockets could play an important role in maintaining the orbits of space stations. With sufficient available power, a plasma engine could also be used to nudge an incoming asteroid away from a collision path with Earth, or even to preposition it for mining operations. Indeed, in the more distant future, fusion-driven plasma rockets could be instrumental in carrying us far beyond our fragile planet, possibly ensuring the survival of the human species.

References and Suggested Reading:
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