A Study and Brief Research On Electric propulsion Of Spacecraft and Rockets

A.Hemant Kumar Yadav[1] ,V.V.S.Nikhil Bharadwaj[2],Kundanam Saikiran[3], D.Rahul Rao[4]
P. Naga Sudeepthi[5] , Sirsinahal Amulya[6] , A.Venkat Sai[7] , Kalyan Dagamoori[8]

[1]Technical Assistant , Department Of Air frame and Structure , Indian Institute Of Aerospace Technology andManagement (IIASTM) , Kompally , Secunderabad. INDIA.
[2,3,4,5,6] Student , Department Of Aeronautical Engineering , MLR Institute Of Technology , Dundigal , Hyderabad.INDIA.

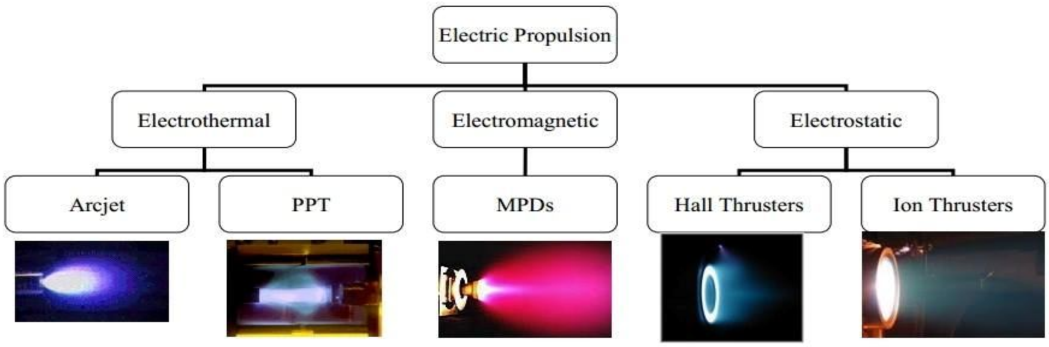
[7] Student , Department Of Mechanical Engineering , MLR Institute Of Technology , Dundigal , Hyderabad.INDIA.

[8] Student , Department Of Aeronautical Engineering , MLR Institute Of Technology and Management , Dundigal , Hyderabad.INDIA.

ABSTRACT
A Research on electric propulsion is presented to serve as an introduction to the more specialized technical papers. The principles of operation and the several types of thrusters that are either operational or in advanced development are discussed . The stimulus for development of electrically drivenspace propulsion systems is nothing less fundamental than Newton's laws of dynamics. Since a rocket propelled spacecraft in free flight derives its only acceleration from discharge of propellant mass, its equation of motion follows directly from conservation of the total momentum of the spacecraft and its exhaust stream. We conclude with a historical summary of the accumulated flight experience using this technology.
Keywords:- Electric propulsion , ion thrusters ,Colliod thruster ,Electrodynamic Theter , rocket , propellant , spacecraft , Pulsed plasma thruster .

1.INTRODUCTION
T his paper is intended to serve as a general overview of the technology of electric propulsion (EP) and its applications, and to lead the interested reader to the more specific technical papers on the topic that are also included in this Special Issue. It is hoped that this series of papers wil be of use not only to the propulsion specialist, but also to spacecraft (S/C) designers seeking to familiarize themselves with a tech nology that is now seeing rapid introduction. EP is by no means a new concept, having first been tested in flight in the 1960s. However, its introduction as a practical alternative to chemical thrusters for S/C propulsion has been slow in developing, owing to a combination of insufficient on board elecrical power on most S/C, and a reluctance by many mission planners to abandon tried and true solutions. The potential performance advantage of primary EP for space missions with large requirements was recognized from the beginning, and much of the early research and development work addressed this type of mission. Yet, it has been the gradual application of the simpler forms of EP to secondary propulsion tasks that has led to its acceptance, with the long envisioned deep -space applications only now beginning to materialize. We first review the existing and emerging types of EP devices and their power sources, with some comments about their relative position in the mission spectrum. The missions themselves are examined to highlight the differences in planning that EP introduces. This is amplified in a brief review of the new S/C integration issues brought about by these thrusters. A summary is included of the flight experience accumulated up to the present time.

2.HISTORY
The idea of electric propulsion for spacecraft dates back to 1911, introduced in a publication by KonstantinTsiolkovsky. Earlier, Robert Goddard had noted such a possibility in his personal notebook. The first in-spacedemonstration of electric propulsion was an ion engine carried on board the SERT-1 (Space Electric RocketTest) spacecraft, launched on 20 July 1964. The Ion Auxiliary Propulsion System (IAPS) project from 1974 to1983 developed an 8-centimeter mercury Ion Propulsion System (IPS) for satellite station keeping. The NASASolar Technology Application Readiness (NSTAR) project developed a 30-centimeter IPS that was used as themain propulsion on the Deep Space 1 (DS1) spacecraft from 1998 to 2001. DS1 was the first use of electricpropulsion for spacecraft main propulsion. The NSTAR thruster on DS1 propelled the spacecraft 263,179,600kilometres (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.



A.Components

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.

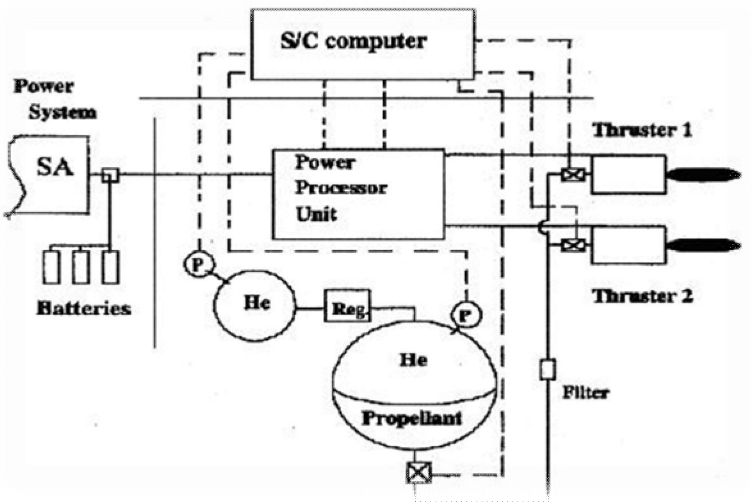


Figure :1 -Schematic of a typical EP system

B.Conceptual Subdivision

Historically, conceptually, and pragmatically, this field has tended to subdivide in the following categories:

1. Ion/plasma drives: This type of rocket-like reaction engine uses electric energy to obtain thrust from propellant carried with the vehicle. They don't necessarily have a rocket nozzle.

i) Electrothermal propulsion, wherein the propellant is heated by some electrical process, then expanded through a suitable nozzle

ii) Electrostatic propulsion, wherein the propellant is accelerated by direct application of electrostatic forces to ionized particles

iii) Electromagnetic propulsion, wherein the propellant is accelerated under the combined action of electric and magnetic fields

2. Non-ion drives:

i) Electrodynamic tethers(EDTs), are long conducting wires, such as one deployed from a tether satellite, which can operate on electromagnetic principles as generators, by converting their kinetic energy to electrical energy, or as motors, converting electrical energy to kinetic energy.

Over their periods of development, each of these approaches has spawned its own array of technical specialties and subspecialties, its own balance sheet of advantages and limitations, and its own cadres of proponents and detractors, but in serious assessment, each has validly qualified for particular niches of application, many of which do not seriously overlap. Throughout the history of EP development, the original subdivision of the field into electrothermal, electrostatic, and electromagnetic systems has remained useful, and this subdivision will be respected through the balance of this article. It should be recognized, however, that in virtually all practical systems, two or even all three of these processes function in some concert to accelerate, channel, and expand the propellant flow, and in many cases it is the efficacy of this cooperation that determines the utility of any given device.

C.Electrothermal Propulsion

The electrothermal category groups the devices where electromagnetic fields are used to generate plasma to increase the temperature of the bulk propellant. The thermal energy imparted to the propellant gas is then converted into kinetic energy by a nozzle of either solid material or magnetic fields. Low molecular weight gases (e.g. hydrogen, helium, ammonia) are preferred propellants for this kind of system. An electrothermal engine uses a nozzle to convert the heat of a gas into the linear motion of its molecules so it is a true rocket even though the energy producing the heat comes from an external source.

(i).Resistojets
(ii). Arcjets

Resistojets

A resistojet is a method of spacecraft electric propulsion that provides thrust by heating a (typically nonreactive) fluid. Heating is usually achieved by sending electricity through a resistor consisting of a hot incandescent filament, with the expanded gas expelled through a conventional nozzle. Resistojets have beenflown in space since 1965 on board military Vela satellites, however they became used in commercialapplications in 1980 with launch of first satellites in the INTELSAT-V program. Now adays resistojet propulsionis used for orbit insertion, attitude control, and deorbit of LEO satellites, including satellites in the Iridiumsatellite constellation and do well in situations where energy is much more plentiful than mass, and where propulsion efficiency needs to be reasonably high but low thrust is acceptable.

Figure :2 - Resistojet

Resistojets operate by passing the gaseous propellant around an electrical heater (which could be the inside of tubes heated radiatively from the outside), then using a conventional nozzle to generate thrust. The heating reduces the gas flow rate from a given upstream pressure through a given nozzle area, thus leading to thefamiliar increase in specific impulse as $\sqrt{\ }$_. Nearly any gas could be used (as long as it is compatible with the high-temperature heater), and this may be dictated by considerations such as waste disposal on manned S/C. The most successful application has been based on the superheating of catalytically decomposed hydrazine, whichhas the advantage of commonality with familiar fuel systems used in hydrazine monopropellant applications.The heaters can operate over the wide pressure range encountered with blowdown systems, and their inputvoltage is low enough to require no special power conditioning, except for current surge protection. Anexception to this would be an S/C power system that would allow more than about 20% voltage variations, in which case a dedicated regulator would become necessary. Operation can continue in a nonsuperheated mode incase of heater failure. The plume is not ionized and poses no unusual S/C interaction problems. Because the molecular mass of the gas ($N_2/H_2/NH_3$) is relatively high, and because the heating wall is limited by materials (W–Re or something similar) to about 2000 K, the specific impulse (Isp) achieved is only modest, of the order of 300 – 310 s. This is 40% better than that without superheating, and the improvement comes at a very small cost in complexity, if power is available. A favourable situation (for this and also for other EP techniques) occurs in geostationary communications satellites, in which excess power is indeed available most of the time (Sec. V), and this prompted the early commercial introduction of hydrazine resistojets (starting with Intelsat V, 1980) for the north–south station keeping (NSSK) function. A more recent application is for orbit insertion, control, and deorbit of the Iridium low Earth orbit (LEO) constellation. One of the few technical problems posed by these thrusters is the tendency of the hydrazine to produce non-volatile deposits at the hot inlet to the catalytic chamber; this is common to all hydrazine thrusters, but the problem is made more critical by the reduction in flow rate because of the higher Isp. Solutions have included the use of ultrapure hydrazine and thermal shunts to reduce heat flux at the critical points. Ammonia resistojets have also been used for higher specific impulse (lighter gas), at some cost in complexity.

Arcjets: Arcjets are a form of electrically powered spacecraft propulsion, in which an electrical discharge (arc) is createdin a flow of propellant (typically hydrazine or ammonia). This imparts additional energy to the propellant, so that one can extract more work out of each kilogram of propellant, at the expense of increased power consumption and (usually) higher cost. Also, the thrust levels available from typically used arcjet engines are very low compared with chemical engines. When the energy is available, arcjets are well suited to keeping stations in orbit and can replace monopropellant rockets

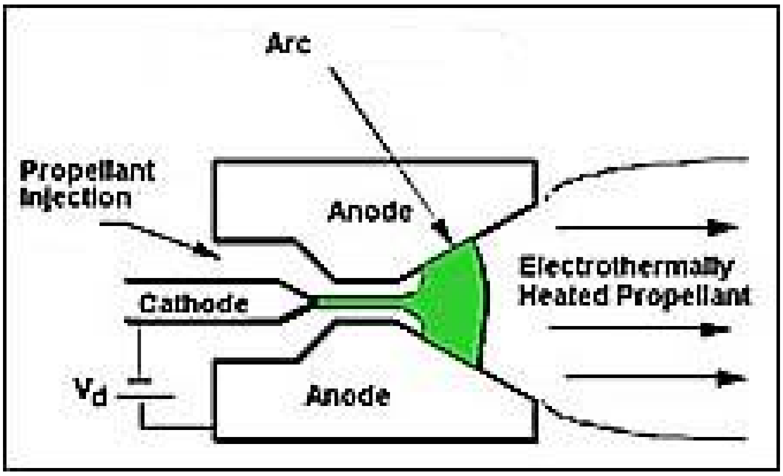


Figure :3-Arcjet

Arcjets are, like resistojets, electrothermal devices, but the wall temperature limitation of the resistojet is overcome here by depositing power internally, in the form of an electric arc, typically between a concentricupstream rod cathode and a downstream anode that also serves as the supersonic nozzle. The flow structure at the throat is extremely non uniform, with the arc core at temperatures of 10,000– 20,000 K, and the buffer layer near the wall at no more than 2000 K. Because of this there is practically no flow through the arc core, which can be thought of as an effective fluid plug; this reduces the flow, without reducing the pressure integral, and leads to the high specific impulse. On the other hand, some intrinsic loss mechanisms are now introduced.

1) Compared with a uniformly heated stream, the nonuniformity reduces by itself the propulsive efficiency because, as in any thermal propulsion device, maximum thrust for a given power and flow is obtained when the heat is added uniformly across the flow.

2) The power invested in ionizing the arc gas is mostly lost because of the small recombination time available (in addition, in molecular gases, there is a substantial dissociation loss as well).

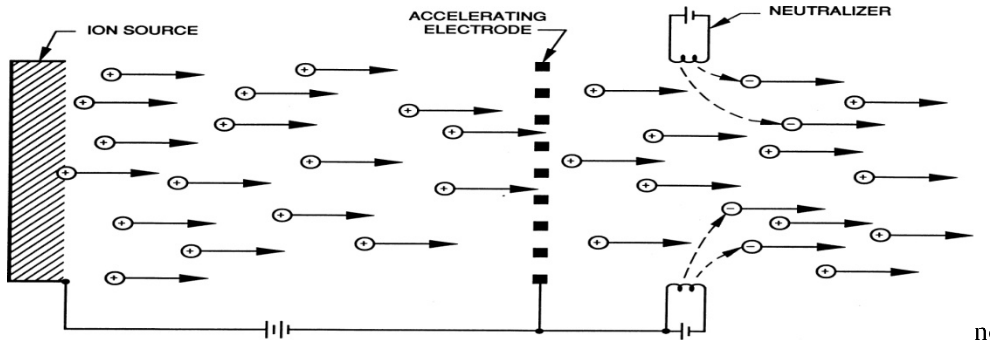
3) There are near-electrode voltage drops, which mainly constitute a local heat loss to the electrodes.

3.ELECTROSTATIC PROPULSION

If the acceleration is caused mainly by the Coulomb force (i.e. application of a static electric field in the direction of the acceleration) the device is considered electrostatic.

1. Electrostatic ion thrusters
2. Colloid ion thrusters

Its key principle is that a voltage difference between two conductors sets up an electrostatic potential difference that can accelerate ions to produce thrust. The ions must, of course, be neutralized--often by electrons emitted from a hot filament. The three main stages of an ion-thruster design are ion production, acceleration, and



neutralization.

Figure : 4 - Ion thruster schematic

a) Ion Sources:

In practice, the most amenable propellants for electrostatic thrusters have proven to be cesium, mercury, argon, krypton, and most commonly xenon, and many possible sources of such ions of the requisite efficiency, reliability, and uniformity have been conceived and developed. Of these, only three, the electron bombardment discharge source, the cesium-tungsten surface contact ionization source, and one form of RF discharge source, have survived to application. The essential elements of the bombardment sources are some form of cylindrical discharge chamber containing a centerline cathode that emits electrons, a surrounding anode shell, and a permeating azimuthal and radial magnetic field that constrains the electrons to gyrate within the chamber long enough to ionize the injected propellant gas and to direct it, once ionized, to extractor and accelerator grids downstream. This particular device employs a hollow cathode electron source, wherein is sustained a secondary discharge that facilitates electron emission from the interior walls of the cathode cavity. The magnetic field permeating the entire chamber is provided by three ring magnets, empirically configured to establish a grossly diverging but doubly cusped field pattern that optimizes the discharge for ionization and ion extraction purposes. The magnitude of this field is adjusted in concert with the anode-cathode voltage differential to maximize the ionization efficiency and discharge stability while minimizing the production of doubly charged ions, which would be out of focus in the accelerator gap and thus tend to erode the grids through high-energy sputtering. Typical values for xenon and mercury propellants would be in the regimes of 0.25 T and 30 V, respectively. Slightly different chamber configurations and field values have also been used successfully.

b) Accelerator Grids:

In virtually all classes of ion thruster, the positive ions are extracted from the source and accelerated downstream by a system of grids configured to achieve the desired exhaust velocity with minimum beam impingement. In U.S. bombardment engines, for example, a double grid configuration is usually dished downstream to improve its mechanical and thermal stability against distortion. The upstream grid is maintained at a higher positive potential than required by the desired exhaust speed in order to enhance the ion extraction process and increase the space-charge limited current density that can be sustained. The downstream grid then reduces the exhaust plane potential to the desired value. This ‘accel-decel’ scheme has the advantages of higher beam density at a given net voltage and of reducing electron back streaming from the neutralized beam downstream. The grid perforations are configured analytically and empirically to focus the ion stream into an array of beamlets that pass through with minimum impingement. In this process, the downstream surface of the discharge plasma in the chamber acts as a third electrode, and since this contour is not independent of the discharge characteristics and applied grid voltages, it can be a source of some instability. Further complicationsare introduced by the small fractions of double ions or neutrals that find their way into the beam and are henceforth out of focus and free to bombard the grid surfaces.

c) Neutralizers:

If the ion beam emerging from the downstream electrode is not to stall on its own interior potential profile, it must be electrostatically neutralized within a very few units of grid spacing. This is typically achieved by provision of a flux of electrons, usually from another hollow cathode discharge, which fortuitously mix effectively within the ion beam by means of a variety of microscopic and macroscopic internal scattering processes. Once so neutralized, this plasma constitutes a downstream ‘virtual electrode’ that completes the axial
potential pattern.

Colloid Ion Thrusters:

A colloid thruster is a type of thruster which uses electrostatic acceleration of charged liquid droplets for propulsion. It is closely related to electrospray ionization and other hydrodynamic spraying processes. In a colloid thruster charged liquid droplets are produced by an electrospray process and then accelerated by a static electric field. The liquid used for this application tends to be a low volatility ionic liquid. Like other ion thrusters its benefits include high efficiency, thrust density, and specific impulse; however it has very low total thrust, on the order of micronewtons. It provides very fine attitude control or efficient acceleration of small spacecraft over long periods of time.

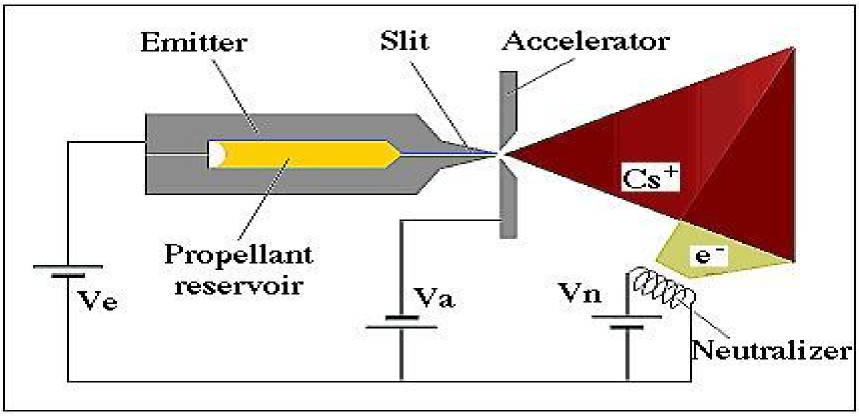


Figure : 5 - Colloid thruster schematic

The original impulse for the development of this type of thruster in the 1960s was the need for thrusters that would yield higher thrust density and would be efficient at lower specific impulse than ion engines. The principle is analogous to that in FEEP, except that a nonmetallic liquid is used, and submicron-sized charged droplets are extracted rather than individual ions. Intensive NASA-led efforts at that time were frustrated by the inability to increase the charge/mass ratio of the extracted droplets sufficiently, which forced the use of very high voltages (several tens to hundreds of kV) to reach the desired specific impulse range (around 1000 s). There was also difficulty in obtaining sprays with nearly uniform values of the charge/mass ratio, which led to poor beam focusing. With continued development of the charged spray technology for applications such as printing and paint application, some of these limits have been relaxed. Russian work20 has led to the development of 65% efficient colloidal engines in the 1000-s specific impulse range that operate with voltages of 15 – 25 kV. This type of thruster would appear to be a leading contender for micro propulsion applications requiring high D*V* at moderately high thrust /power ratios.

4.ELECTROMAGNETIC PROPULSION

If ions are accelerated either by the Lorentz force or by the effect of electromagnetic fields where the electric field is not in the direction of the acceleration, the device is considered electromagnetic.

a. Hall Effect Thruster
b. Magnetoplasmadynamic (MPD) thruster
c. Pulsed Plasma Thruster

Such systems can produce exhaust speeds considerably higher than those of the electrothermal devices, and thrust densities much larger than those of the electrostatic thrusters, but are phenomenologically more complex and analytically less tractable than either of these alternatives. The essence of an electromagnetic thruster is sketched, where some electrically conducting fluid, usually a highly ionized gas, is subjected to an electric field $\boldsymbol{E}$ and a magnetic field $\boldsymbol{B}$, perpendicular to each other and to the fluid velocity $\boldsymbol{u}$. The current density $\boldsymbol{j}$ driven by the electric field interacts with $\boldsymbol{B}$ to provide a streamwise body force $\boldsymbol{f} = \boldsymbol{j} \times \boldsymbol{B}$ that accelerates the fluid along the channel. The process may alternatively be represented from a particulate point of view in terms of the mean trajectories of the current-carrying electrons, which, in attempting to follow the electric field, are turned downstream by the magnetic field, transmitting their streamwise momentum to the heavy particles in the stream by collisions and/or by microscopic polarization fields. It is important to note that in either representation, the working fluid, although highly ionized, is macroscopically neutral, hence not constrained in its mass flow density by space-charge limitations as in the electrostatic accelerators.

a. Hall Effect Thruster

In spacecraft propulsion, a Hall thruster is a type of ion thruster in which the propellant is accelerated by an electric field. Hall thrusters trap electrons in a magnetic field and then use the electrons to ionize propellant, efficiently accelerate the ions to produce thrust, and neutralize the ions in the plume. Hall thrusters are sometimes referred to as Hall Effect thrusters or Hall current thrusters. Hall thrusters are often regarded as a moderate specific impulse (1,600 s) space propulsion technology. The Hall Effect thruster has benefited from considerable theoretical and experimental research since the 1960s. 6 kW Hall thruster in operation at the NASA Jet Propulsion Laboratory. Hall thrusters operate on a variety of propellants, the most common being xenon. Other propellants of interest include krypton, argon, bismuth, iodine, magnesium, and zinc. Hall thrusters are able to accelerate their exhaust to speeds between 10–80 km/s (1,000–8,000 s specific impulse), with most models operating between 15–30 km/s (1,500–3,000 s specific impulse). The thrust produced by a Hall thruster varies depending on the power level. Devices operating at 1.35 kW produce about 83 mN of thrust. High power models have demonstrated up to 3 N in the laboratory. Power levels up to 100 kW have been demonstrated by xenon Hall thrusters. Today's Hall thrusters are sometimes referred to as 'closed-electron-drift' devices, given the azimuthal drift electrons that is common to all present variants of such thrusters. The most common versions are the stationary plasma thruster (SPT) (also termed the 'magnetic layer thruster') and the anode layer thruster (ALT). The former differs from the latter by its extended channel, the use of insulator chamber walls, and the extent of the quasineutral acceleration region, but both rely on the same basic principles for ionizing and accelerating the propellant.

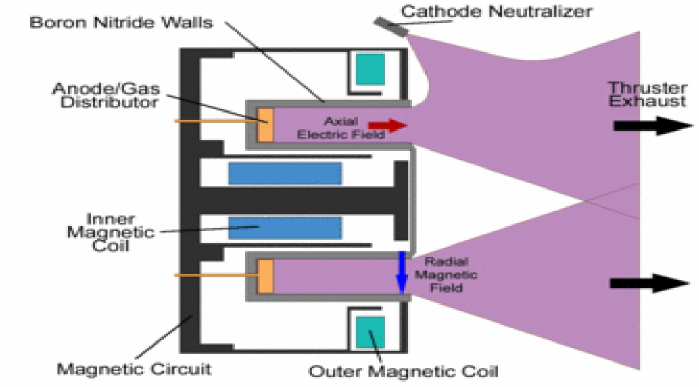


Figure : 6 - Hall Effect Thruster

Electrons from the cathode enter the chamber and are subjected to an azimuthal drift in the crossed radial magnetic and axial electric fields, wherein they undergo ionizing collisions with the neutral propellant atoms (typically xenon) injected through the anode. While the magnetic field strength is sufficient to lock the electrons in an azimuthal drift, it does not significantly affect the trajectory of the ions, which are directly accelerated by the axial electric field. An axial electron flux equal to that of the ions reaches the anode due to a cross field mobility that often exceeds classical values, and the same flux of electrons is available from the cathode to neutralize the exhausted ions. Quasi-neutrality is thus maintained throughout the chamber and exhaust beam, and consequently no spacecharge limitation is imposed on the acceleration, which allows relatively high thrust densities compared with those of conventional electrostatic propulsion devices. Nominal operating conditions of a common flight module (e.g., the Russian SPT-100) operating with xenon are a 2- 5mg/sec mass flow rate; a 200- to 300-V applied voltage, yielding a plasma exhaust velocity of 16,000 m/sec; and a thrust of 40-80 mN, at efficiencies of about 50%.

b. Magnetoplasmadynamic (MPD) Thruster

In MPD thrusters, a current along a conducting bar creates an azimuthal magnetic field that interacts with the current of an arc that runs from the point of the bar to a conducting wall. The resulting Lorentz force has two
components:
Pumping: a radially inward force that constricts the flow.
Blowing: a force along the axis that produces the directed thrust.

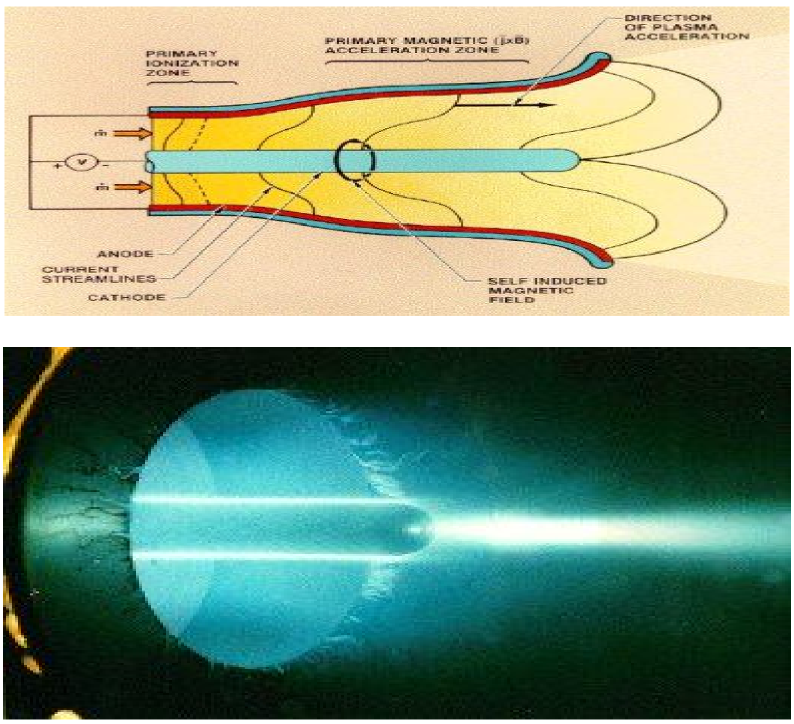


Figure :7 -(MPD) Thruster

The magnetoplasmadynamic (MPD) thruster is characterized by a coaxial geometry constituted by a centralcathode, an annular anode, and some form of interelectrode insulator. Gaseous propellants are introduced intothe upstream portion of the channel, whereafter they are ionized by passage through an intense, azimuthallyuniform electric arc standing in the interelectrode gap. If the arc current is high enough, its associated azimuthalmagnetic field is sufficient to exert the desired axial and radial body forces on the propellant flow, directly accelerating it downstream and compressing it toward the centerline into an extremely hot plasma just beyondthe cathode tip. Subsequent expansion of this plasma, along with the direct axial acceleration, yields therequisite exhaust velocity.The MPDT has demonstrated its capability of providing specific impulses in the range of 1500-8000 sec withthrust efficiencies exceeding 40%. High efficiency (above 30%) is typically reached only at high power levels(above 100 kW); consequently, the steady-state version of the MPDT is regarded as a high-power propulsion option. When the thruster is operated below 200 kW, the self-induced magnetic field becomes only marginallysufficient to provide the desired body force, and external fields are frequently added to enhance performance in this range. However, in its megawatt versions, the self-field MPDT has the unique capability, among all developed electric thrusters, of processing very high power levels in a simple, compact, and robust device that can produce thrust densities as high as 10^5 N/m^2. These features have rendered the steady state MPDT particularly attractive for energetic deep-space missions requiring high thrust levels, such as piloted and cargo missions to Mars and the outer planets, as well as for nearer-term orbit raising missions.

c. Pulsed Plasma Thruster

A Pulsed Plasma Thruster (PPT), also known as a plasma jet engine, is a form of electric spacecraft propulsion. PPTs are generally considered the simplest form of electric spacecraft propulsion and was the first form of electric propulsion to be flown in space, having flown on two Soviet probes (Zond 2 and Zond 3) starting in 1964. PPTs are generally flown on spacecraft with a surplus of electricity from abundantly available solar energy.

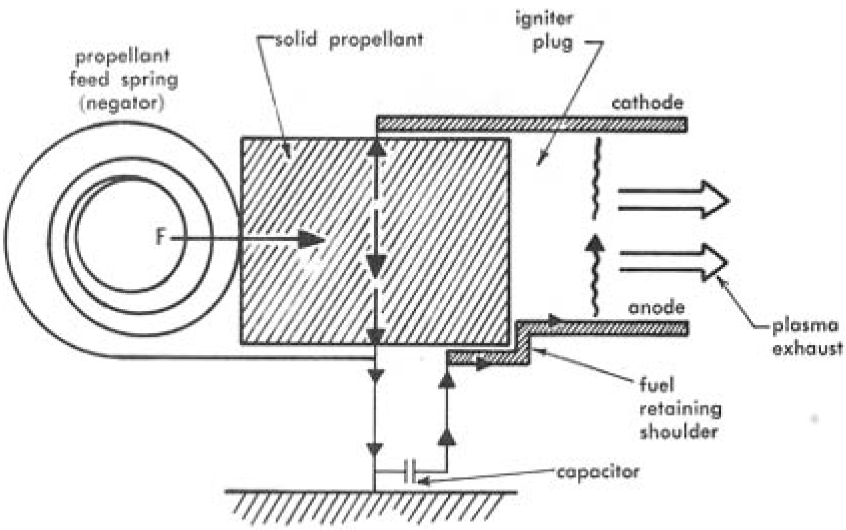


Figure : 8- Pulsed Plasma Thruster

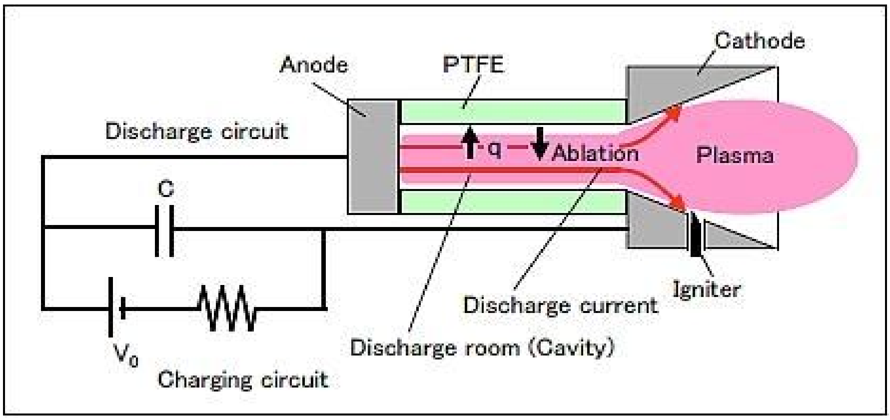


Figure :9- Schematic view of the PPT

Most PPTs use a solid material (normally PTFE, more commonly known as Teflon) for propellant, although a minority use liquid or gaseous propellants. The first stage in PPT operation involves an arc of electricity passing through the fuel, causing ablation and sublimation of the fuel. The heat generated by this arc causes the resultant gas to turn into plasma, thereby creating a charged gas cloud. Due to the force of the ablation, the plasma is propelled at low speed between two charged plates (an anode and cathode). Since the plasma is charged, the fuel effectively completes the circuit between the two plates, allowing a current to flow through the plasma. This flow of electrons generates a strong electromagnetic field which then exerts a Lorentz force on the plasma, accelerating the plasma out of the PPT exhaust at high velocity the pulsing occurs due to the time needed to recharge the plates following each burst of fuel, and the time between each arc. The frequency of pulsing is normally very high and so it generates an almost continuous and smooth thrust. While the thrust is very low, a PPT can operate continuously for extended periods of time, yielding a large final speed. The energy used in each pulse is stored in a capacitor. By varying the time between each capacitor discharge, the thrust and power draw of the PPT can be varied allowing versatile use of the system. PPTs are very robust due to their inherently simple design (relative to other electric spacecraft propulsion techniques), and draw very little electrical power relative to other comparable thrusters. As an electric propulsion system, PPTs benefit from reduced fuel consumption compared to traditional chemical rockets, reducing launch mass and therefore launch costs, as well as high specific impulse improving performance. However, due to energy losses caused by late time ablation and rapid conductive heat transfer from the propellant to the rest of the spacecraft, propellant efficiency is very low compared to other forms of electric propulsion, at around just 10%.

Type	Thrust Range (mN)	Specific Impulse (sec)	Thruster Efficiency (%)	Thrust Duration	Typical Propellant	Kinetic Power per Unit Thrust (W/mN)
Resistojet (thermal)	200-300	200-350	65-90	Months	NH3, N2H4, H2	0.5-6
Arcjet (thermal)	200-1000	400-1000	30-50	Months	H2, N2, N2H4, NH3	2-3
Ion thruster	0.01-200	1500-5000	60-80	Months	Xe, Kr, Ar	10-70
PPT	0.05-10	600-2000	10	Years	Teflon	10-50
MPD	0.001-2000	2000-5000	30-50	Weeks	Ar, Xe, H2, Li	100
Hall thruster	0.01-2000	1500-2000	30-50	Months	Xe, Ar	100
Monopropellant rocket	30-100,000	200-250	87-97	Hours or Minutes	N2H4	

5.ELECTRODYNAMIC TETHERS

As part of a tether propulsion system, crafts can use long, strong conductors (though not all tethers are conductive) to change the orbits of spacecraft. It has the potential to make space travel significantly cheap. It is a simplified, very low-budget magnetic sail. It can be used either to accelerate or brake an orbiting spacecraft. When direct current is pumped through the tether, it exerts a Lorentz force against the magnetic field, and the tether accelerates the spacecraft. In 2012, the company Star Technology and Research was awarded a $1.9 million contract to qualify a tether propulsion system for orbital debris removal.

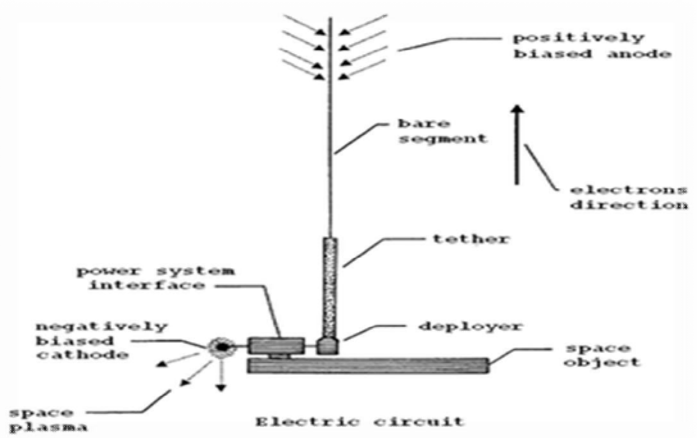


Figure : 10- Electrodynamic Tether

Over the years, numerous applications for electrodynamic tethers have been identified for potential use in industry, government, and scientific exploration. The table below is a summary of some of the potential pplications proposed thus far. Some of these applications are general concepts, while others are well-defined systems. Many of these concepts overlap into other areas; however, they are simply placed under the most appropriate heading for the purposes of this table. All of the applications mentioned in the table are elaborated upon in the Tethers Handbook. Three fundamental concepts that tethers possess are gravity gradients, momentum exchange, and electrodynamics.

6.FUTURE OF ELECTRIC PROPULSION

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 orimpossible 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. The Jupiter Icy Moons Orbiter (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. 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 humankind to explore the farthest reaches of our solar system.

7.CONCLUSION

Many concepts of the future technologies are yet in embryonic stages and are being researched across the globe. These discussed techniques are the ideas of those few unique brains which could lift the mankind to heavens and could propel the human pride beyond the galactic frontiers with their ineffable intelligence and their indescribable imagination. Lets hope that these concepts would very soon be called as technologies because, the world of today was built on fantasies of yesterday.

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2. Vatsal Sheth - Mechanical Engineering Dept. Dwarkadas J. Sanghvi College of Engineering, Mumbai

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