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Review

Application of plasma technology in aerospace vehicles: A review

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The galactic and solar radiation effects on astronauts in space during manned-space missions is one of the issues that scientists are dealing with to come up with a reasonable solution to overcome this disaster. Furthermore, in space missions to Mars, Titan, and beyond them, a powerful propulsion system is required. Recently, with the enhancement of technology in plasma generation, scientists are trying to design and build a plasma radiation shield and plasma propulsion system to create a safe and reliable space-craft for long-term space missions. To produce a plasma radiation shield and/or plasma propulsion system, a strong magnet to generate a magnetic field for electron cloud is required. For charging magnets, appropriate power supplies or fuel cells are needed. Additionally, to create a solid shield against the radiation on crafts skin, some coatings with plasma glow discharge can be deposited. This review focused on the mechanism for plasma radiation shield, different plasma propulsion systems, and different plasma deposited films for space-craft shielding against the radiation. Observations from this review have indicated that the application of plasma technology as a radiation shield, propulsion system, and a tool to produce space-crafts coating seems very promising and helpful for future space missions. However, it is required that practical experiments and financial assessments are considered.

Key words: Galactic cosmic ray, solar particle event, plasma radiation shield, plasma propulsion system, magnet power supply, astronauts' health.

INTRODUCTION

With the investigation of manned-space missions, it is easy to find out that one of the major issues in manned-space missions is the radiation effects on astronauts. This problem exists during the space-travel. Furthermore, this issue does not just exist in space or beyond the Earth Orbit, it also exist in some planets such as Mars because it appears that the Mars' atmosphere has a very small thickness in comparison with the Earth's atmosphere (Pasachoff, 1993). Thus, it is not capable of building an adequate shield against solar and cosmic radiation. As a result, it is considered as a health-risk for crew such as possibility of causing cancer, other illnesses, and even death in worst cases (Cucinotta et al., 2005; Horneck and Comet, 2006).

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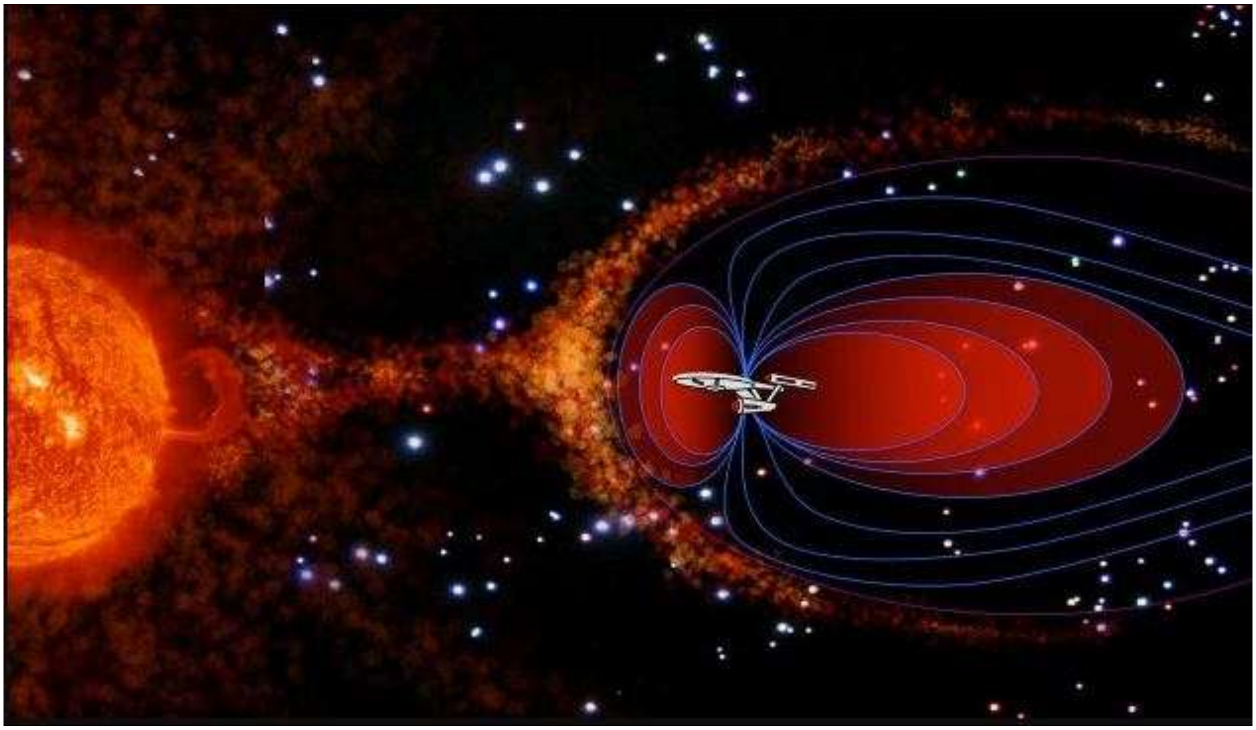


Figure 1. Schematic of the plasma radiation shield applied in space-vehicle encountering solar flare.
Source: CNN: Dave Gilbert, July 2 (2013)

Currently, it has been discovered that plasma technology can be applied in space-vehicles to solve radiation issues for astronauts by eliminating the radiation effects in space-missions (Diaz and Seedhouse, 2017). Even the application of plasma technology in space-crafts can contribute to generating the high-power propulsion system for future space-missions to Mars and beyond that (Diaz and Seedhouse, 2017).

For applying the plasma technology in space-vehicles, there would be some requirements such as some components to attach to space-crafts structure for operating the plasma within the space-missions. These components include, but not limited to magnet that creates the magnetic field for the electron cloud to produce the shield against the solar and cosmic radiation, and power supplies such as fuel cells that empowers or charges the magnet. There are many types of power supplies that can be used to charge the magnet during the space missions to generate the radiation shield. Each of these power supplies have different operating temperatures. Hence, when the magnet is on to activate the radiation shield, the temperature of space vehicle is affected by this operating temperature. On the other hand, when the magnet is off, the temperature of the space-craft will tend to the temperature of the space environment. Consequently, thermal cycles will be created. These thermal cycles have effect on the thermal fatigue life of the space-vehicles structures (Anvari 2018). Many space-vehicles have been currently built with carbon materials. In Figures 1 and 2, the schematic representing the plasma radiation shield applied in space-vehicles are illustrated (CNN: Dave Gilbert, July 2, 2013).

Radiation and its effects on human health

Space-missions beyond the Earth Orbit may be exposed to Galactic Cosmic Rays (GCRs) and/or Solar Particle Events (SPEs) from solar flares. These space incidents comprised high-energy particles with high-velocity that are capable of penetrating into the most of the materials, including human-body tissues. Consequently, these particles can shred genetic material and cause many illness-symptoms. At high dosage, these radiation particles may result in cancer and even death of the astronauts. Scientists estimated that radiation absorption during the mission to Red planet could increase the risk of cancer for crew by maximum of five percent (Diaz and Seedhouse, 2017).

Furthermore, the risk of illness for female astronauts due to radiation is 20% higher than that for men. The reason for this is higher risk due to ovarian, breast, and uterine cancers. Additionally, radiation appears to be a capricious hazard. Long-term exposure to radiation may harm the immune system, disturb the short-term memory,

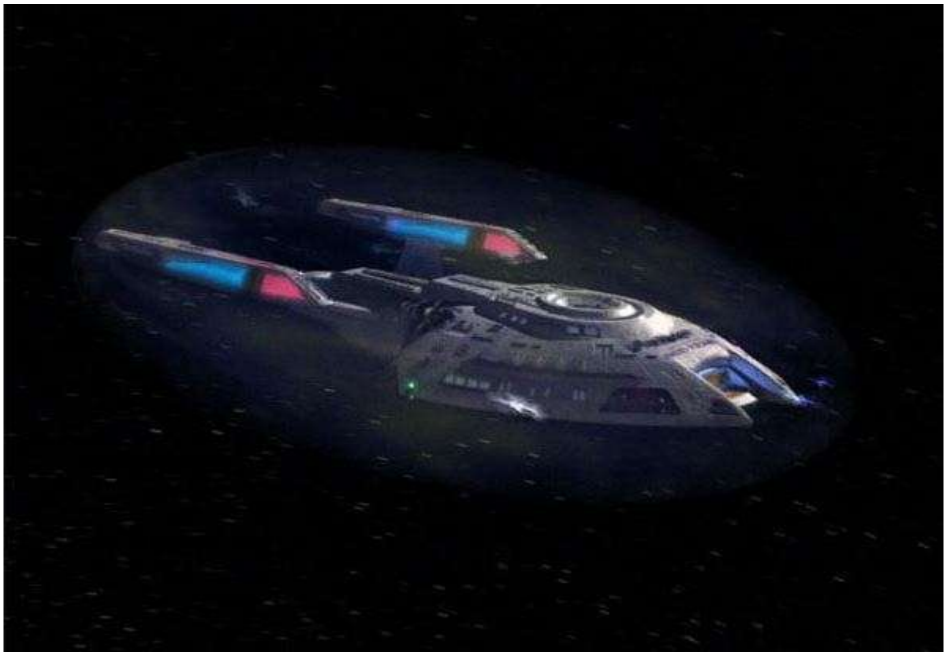


Figure 2. Schematic of the plasma radiation shield applied in space-vehicle in space.
Source: CNN: Dave Gilbert, July 2 (2013).

cause heart disease, and induce Alzheimer-like symptoms. However, crew members exposed to radiation may also experience nausea, diarrhea, headache, fever, dizziness, fatigue, low blood pressure, etc (Diaz and Seedhouse, 2017).

PLASMA RADIATION SHIELD AND PROPULSION SYSTEM

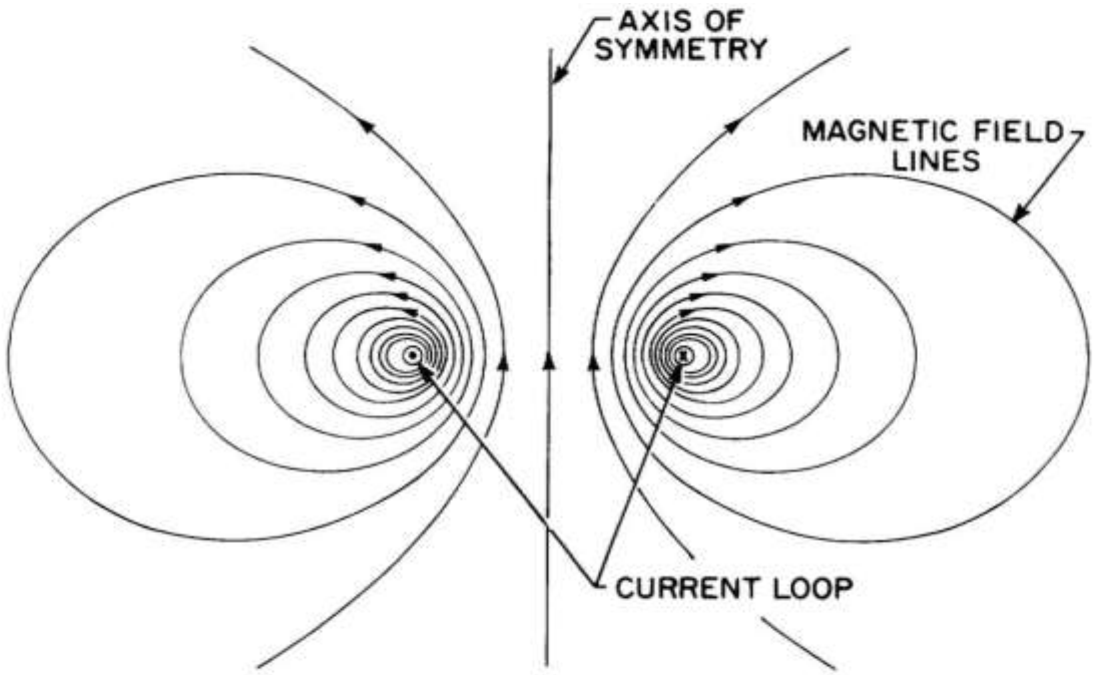
In space missions, space-crafts are exposed to protons that have been released from solar flares. To prevent these protons harming the astronauts' health, the concept of plasma radiation shield has been introduced. However, for generating such a radiation shield with plasma to protect the space-crafts from protons emitted from solar-flare incidents, many factors are required to be considered. These factors may include but not limited to (Levy and French, 1968):

1. Appropriate design.
2. Adequate magnetic field.
3. Equilibrium of electron cloud in dynamic level.
4. Amount of solid shield such as Aluminum.
5. Operational limitations such as in different propulsion conditions and the number of times that plasma radiation shield can be on and off during the space mission.
6. Selection of appropriate magnet charging power supply.
7. The effect of plasma radiation shield on communication systems.
8. Operational procedures for propulsion systems while plasma radiation shield is on.
9. The effect of plasma radiation protection system on crew and their life support.
10. The effect of plasma radiation shield system on electronic equipment.
11. The weight of the magnet system for generating plasma radiation shield.
12. Attaining enough voltages and electron cloud for plasma radiation shield systems generation and stability.
13. Integration of plasma radiation protection and propulsion system into the structure of space-vehicle.

In Figure 3 (Levy and French, 1967), a loop current which represents the simplest shape of magnet capable of satisfying the required system, is shown. This figure shows the form for the lines of the magnetic field surrounding a loop (Levy and French, 1967).

Additionally, in Figure 4 (Levy and French, 1967), loop current adapted to the craft is illustrated. In this figure, the space-vehicle is symmetric around the loop axis. Furthermore, a four-coil arrangement of the super conducting magnet and electron cloud generated in relation to drift direction are shown. As illustrated in the figure, double-walled structure is adapted for plasma radiation shield (Levy and French, 1967).

Moreover, in Figure 5 (Levy and French, 1967), some configurations of space-vehicle generating plasma radiation shield are shown. Basic toroidal form that is appropriate for small space-vehicles is illustrated in 'A', the versions that could be applied in 'B' and 'C' are



A loop current is the simplest form of magnet giving a field shape satisfying the requirements of the Plasma Radiation Shield. This illustration shows the general shape of the magnetic field lines surrounding such a loop.

Figure 3. A loop current which represents the simplest shape of magnetic field that can be applied in space-vehicles as a radiation shield system.
Source: Levy and French (1967).

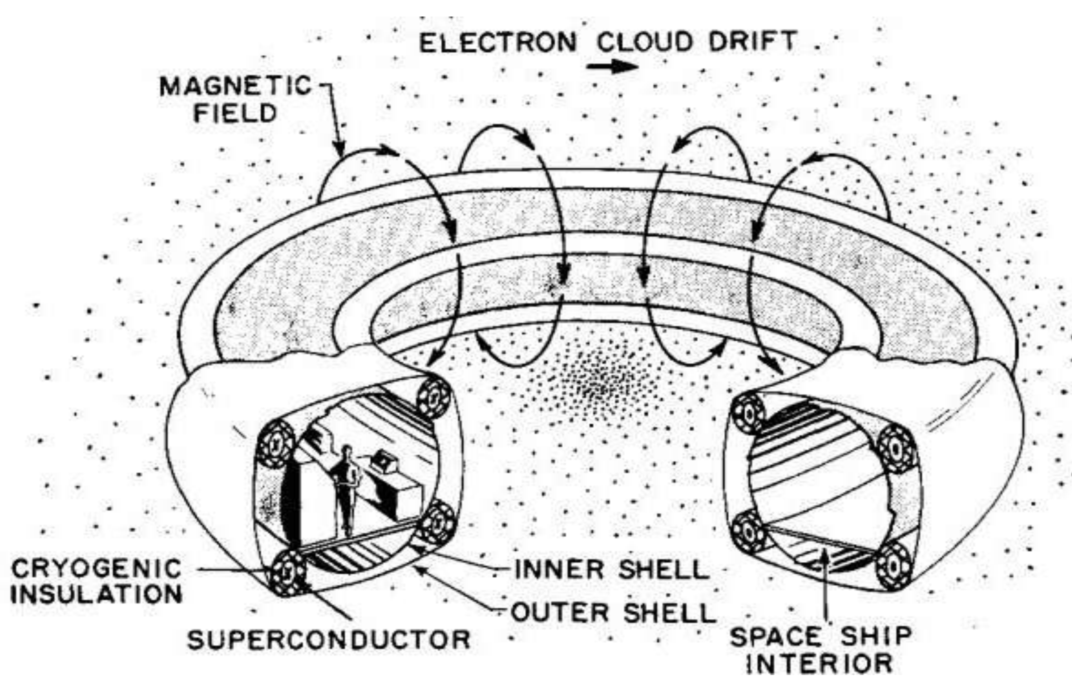


Figure 4. Schematic of a loop current adapted to the space-craft structure.
Source: Levy and French (1967).

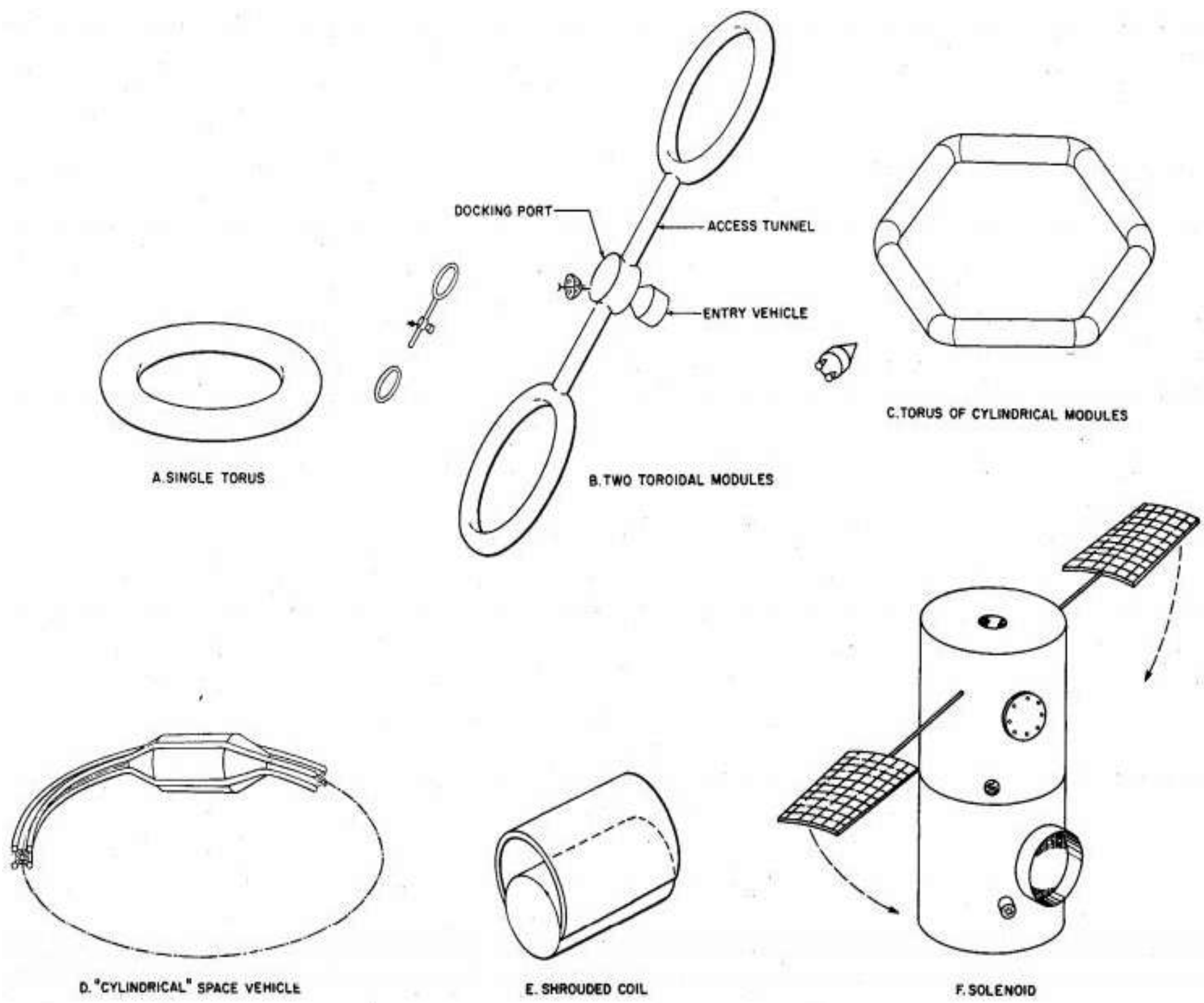


Figure 5. Some conceptual configurations of space-vehicle that generate the plasma radiation protection system. Source: Levy and French (1967).

suitable for intermediate and large size space-crafts. The designs shown in 'D' through 'F' are acceptable according to topological view. The version that is shown in 'D' is cylindrical type which is deployable in orbit, while the version illustrated in 'E' is contained with coil that represents a structure similar to a shroud. Finally, in 'F' a cylindrical coil of wire that acts as a magnet is shown.

In Figure 6 (Levy and French, 1967), a toroidal space-craft applying plasma radiation protection which has a double-wall structure is shown. The pressure between solid walls is held at 10e-9 torr by low temperature of the coils and vacuum pumps.

Furthermore, in Figures 7 and 8 (Levy and French, 1967), a space-craft with toroidal electron plasma and photograph of the apparatus for generating plasma protection system in space-crafts are illustrated, respectively. Electrons flowing into the torus shape are initiated from the filament located in the slot. These electrons are compressed by a magnetic field and can generate a potential along the axis of the circular structure of the device.

For developing plasma radiation shield that will protect the astronauts from protons emitted from solar flare and other cosmic incidents, magnetic and electric fields including free electrons are required. Also, for providing such an integrated system, extremely high voltages are needed (Levy and French, 1967).

Astronauts in space are exposed to solar flare and galactic radiations that are very dangerous for them especially in incidents with high-dose radiations. The lack of an appropriate shielding against the radiation in space-vehicles could result in discomfort of the crew, in severe-radiation incident may cause illness, whereas in extreme cases will result in the death of the crew (Levy and French, 1967).

There exist some procedures to diminish and even eliminate the radiation effect on astronauts during the space missions. One of these methods is the application

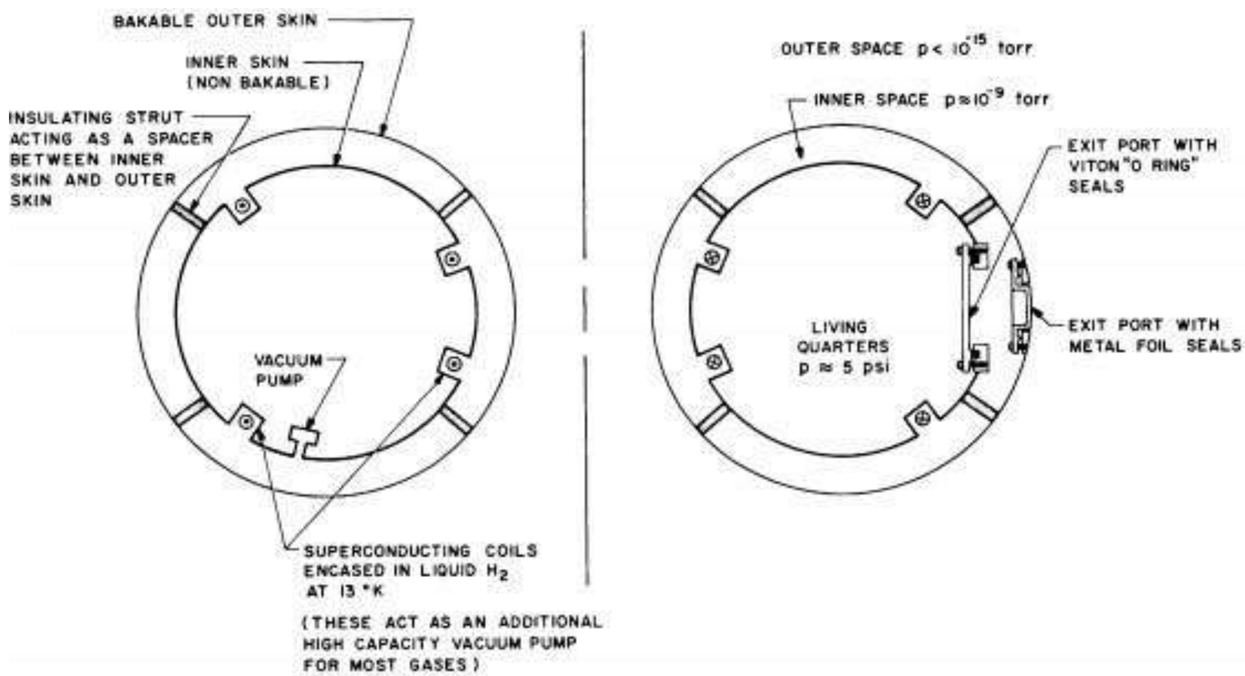
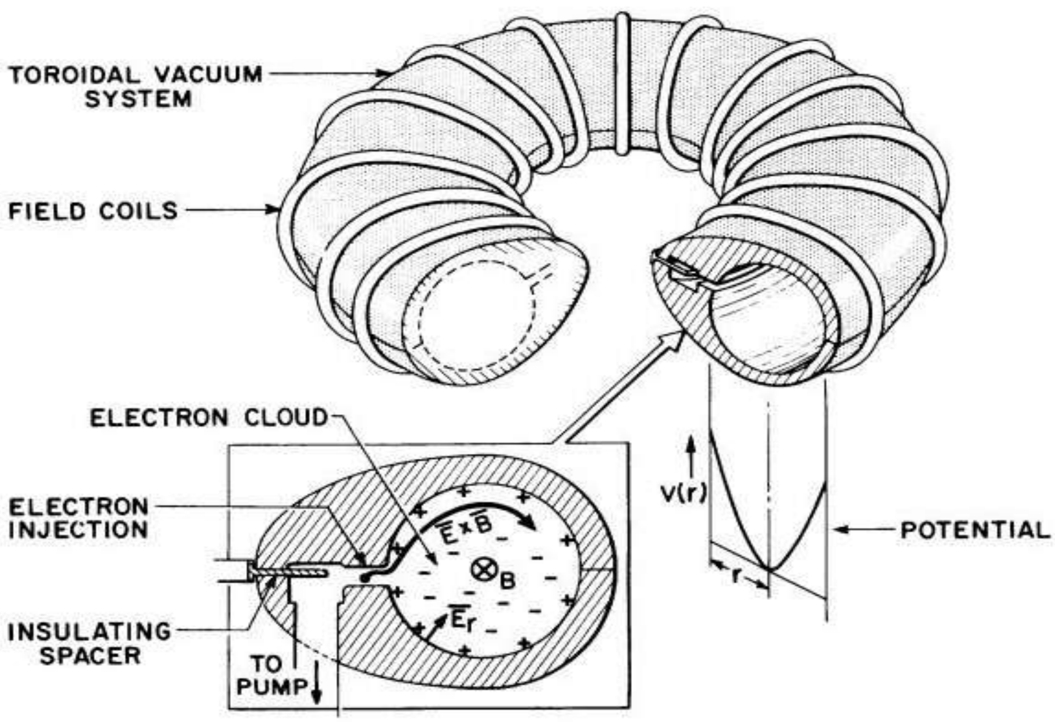
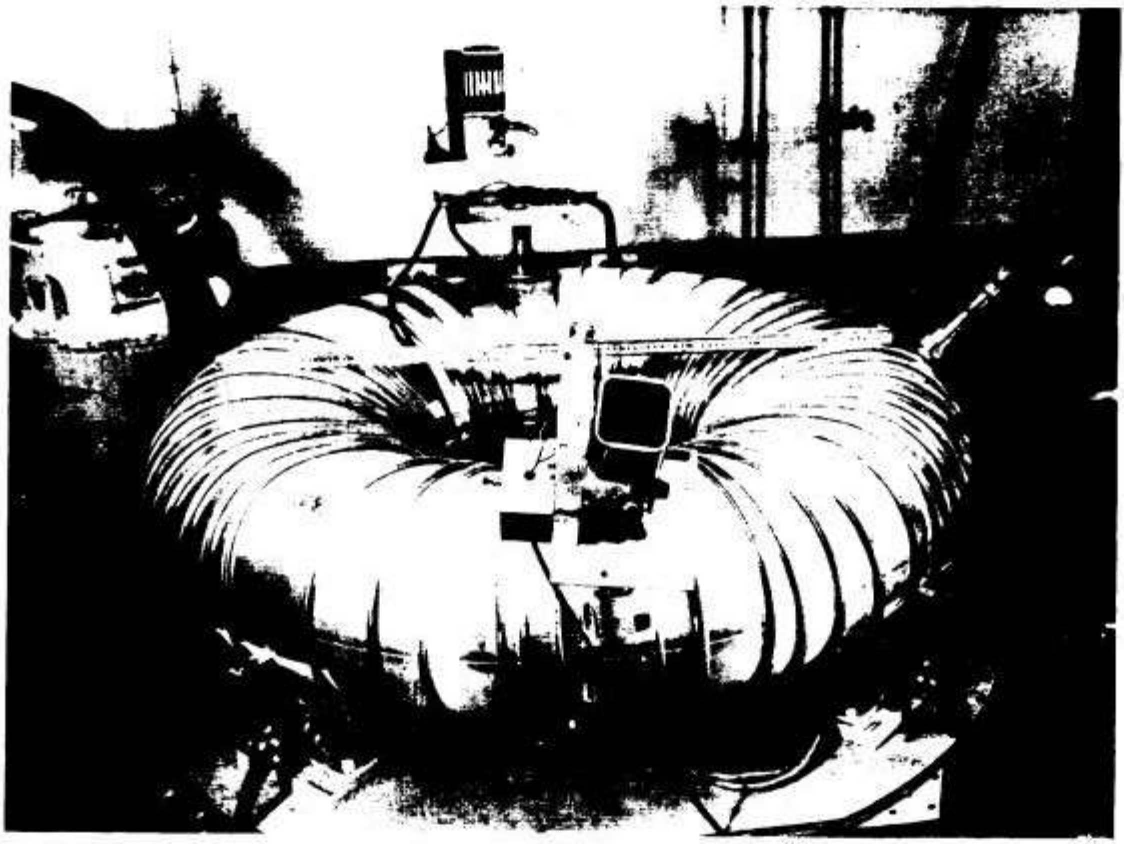


Figure 6. Cross-section of the toroidal space-craft applying plasma radiation protection with a double-wall structure. Source: Levy and French (1967).



Schematic of toroidal electron plasma experiment. Electrons are introduced into the torus from a filament in the slot, compressed by a rising magnetic field, and create a potential depression along the circular axis of the device.

Figure 7. Schematic of a toroidal electron plasma for generating plasma protection system in space-crafts Source: Levy and French (1967).



Photograph of the apparatus shown

Figure 8. Photograph of the apparatus for generating plasma protection system in space-crafts
Source: Levy and French (1967).

of solid materials as a shield on space-crafts structure. The application of polyethylene and aluminum as solid shield shells against the radiation on space-crafts skin are recommended (Levy and French, 1967).

The other method for providing radiation shield for space-crafts is to generate a magnetic field that can hold the electron cloud to build a protection system against the emitted protons. The generation of this magnetic field is possible with the application of plasma technology. In order to create this protection system, a clean outgassed outer layer and one double-walled pressure vessel are required. The pressure should be around 10^{-6} to 10^{-9} mm Hg at interior space between the two walls. For providing such a pressure, vacuum pumps can be used. Furthermore, the magnetic energy should be around 5e+6 Joules (Levy and French, 1967).

There are many types of magnet charging power supplies like Hydrogen-Oxygen and Lithium-Chlorine fuel cells. Hydrogen-Oxygen fuel cells operate at 90°C while Lithium-Chlorine fuel cells operate at 650°C. Hence, it appears that the operating temperature of Hydrogen-Oxygen fuel cell is more pleasant because operating at 650°C for Lithium-Chlorine fuel cell requires special materials and coating that can tolerate this high temperature. However, in case of high-level of power and weight saving, Lithium-Chlorine fuel cells are more beneficial when compared to Hydrogen-Oxygen fuel cells. Nevertheless, there are some instructions during operation of plasma radiation shield. It seems that propulsion systems are not allowed to have exhaust while the plasma protection system is in-operation and may require to be shut down (Levy and French, 1967).

Application of plasma technology is not just limited to plasma radiation shield technology. Plasma spraying can be used to produce thin layers of polytetrafluoroethylene that protects space-vehicles from oxygen particle degradation. This protective coating can be applied to copper radiating patches, epoxy, and other substrates. The thickness of this film is 0.5 to 0.7 µm (Zimcik et al., 1991).

It is interesting to mention that natural plasmas in space environment are very frequent. Plasmas are also being found in interstellar clouds, planetary rings, ionosphere of the Earth, and Cometary plasma tails. Plasma has also been observed in radial spokes of Saturn's B ring and in the interaction of cometary tails with solar wind (Kotsarenko et al., 1998).

In regard to the development of space-crafts protection system against radiation and generating propulsion, magnetic shielding and using superconductors in plasma protecting system have been introduced. For this purpose, a four-coil superconducting magnet has been proposed (Goksel and Rechenberg, 2003).

For generating adequate coating for materials used in lightweight space-crafts, the process of plasma electrolytic oxidation is proposed. This coating may be applied to materials such as light metals and their alloys. The final product of this procedure is a ceramic layer. For developing coating for aluminum alloys, Keronite plasma electrolytic oxidation is used. For this purpose, plasma discharge should be created around a component that is immersed in an electrolyte (Shrestha and Dunn, 2007).

The concept of shielded space-craft with the application of plasma technology can be presented as a dipole-like magnetic field surrounding a space-vehicle developing a "mini-magnetosphere." This technology can contribute to maintaining the safety of astronauts in case of solar wind incidents by creating a "hole" in solar flare-produced proton environment. Additionally, mini-magnetosphere structures can be used to empower the space-crafts propulsion (Bamford et al., 2008).

In Figure 9 (Bamford et al., 2014), a magnetically kept plasma barrier generating an artificial shielding mini-magnetosphere around the space-vehicle is shown. The plasma generated around the space-craft is created by supersonic hydrogen. Figure 10 (Bamford et al., 2014) illustrates the solar wind which is encountering the plasma barrier from left and flowing to the right direction. The held plasma creates a sheath shield that diverts the solar flare and prevents its impact to the space-vehicle (Bamford et al., 2014).

In Figure 10 (Bamford et al., 2014), a plasma radiation protection system is shown. In this plasma shield, electric field deflects the energetic ions and avoids encountering the hazardous particles striking the space-vehicle. The plasma protection system is retained by releasing ionized gas emitted from the space-craft which is capable of generating protection with at least 100 MeV/amu ions (Bamford et al., 2014). Additionally, in Figure 11 (Bamford et al., 2014), a conceptual design of manned interplanetary craft is presented (Bamford et al., 2014).

The mini-magnetosphere plasma that is capable of providing protection against solar wind and generating propulsion is predicted to expand out about several 100 km to a few thousand km in radius. It has been estimated that mini-magnetosphere with this feature is capable of withstanding and coping with energetic particles emitted from galactic rays and solar flares. However, this plasma protection system requires about 100 kW maintained power to operate the mini-magnetosphere. Furthermore, 0.1 to 1 T magnetic field is also required to support the magnet (Winglee et al., 2011).

In interplanetary space, solar wind incidents are possible. These events are contained with the flow of particles such as protons and electrons emitted from the sun. These particles are solar energetic particles. For the protection of crew against these high-energy particles, plasma radiation shield system is recommended which consists of equal numbers of ions and electrons with high temperatures. These hot ions and electrons in plasma are capable of diminishing the hazardous effects of radiation in space and secure astronauts from the harmful radiation effects during the space-missions. Moreover, plasma beams or directed ions can also be used to empower the propulsion system of the space-vehicle (Bamford et al., 2014).

In case of the application of plasma for the shielding system of the space-crafts against the radiation, use of cold plasma such as krypton or xenon gas can increase the effectiveness of the protection system by ionizing with UV-radiation emitted from solar wind and storm events. For maintaining adequate energy for plasma radiation shield system, an on-board power supply is necessary. Additionally, for the safety and health of the crew on-board in space-vehicles, passive or biological shielding equipment against the radiation is also recommended. The evidence that proves mini-magnetosphere can be used as plasma radiation shield comes from the space around asteroids and comets, and anomalies on the moon (Bamford et al., 2014).

Power supplies for magnet charging

To provide both manned and unmanned space-crafts with power to operate, different types of power supplies such as fuel cells are produced (Warshay and Prokopius, 1989; Fuel Cell Handbook, 2004; Rahman et al., 2015; Jakupca, 2018). It appears that available fuel cells and power supplies with the potential to generate power for manned and unmanned space-vehicles are as follows:

1. Proton Exchange Membrane fuel cell (PEM) with 4.4 to 93.3°C operating temperatures (Vasquez et al., 2017).
2. GenCore 5B48 Hydrogen fuel cell with -40 to 46°C operating temperatures (Birek and Molitorys, 2009).
3. Single-sided Magneto Hydrodynamic (MHD) power plant with plasma propulsion with 27°C operating temperature (Diaz and Seedhouse, 2017).
4. Double-sided Magneto Hydrodynamic (MHD) power plant with plasma propulsion with 327°C operating temperature (Diaz and Seedhouse, 2017).
5. Polymeric Electrolyte Membrane Fuel Cell (PEMFC) with 120°C operating temperature (Giorgi and Leccese 2013).
6. Direct Methanol Fuel Cells (DMFC) with 120°C operating

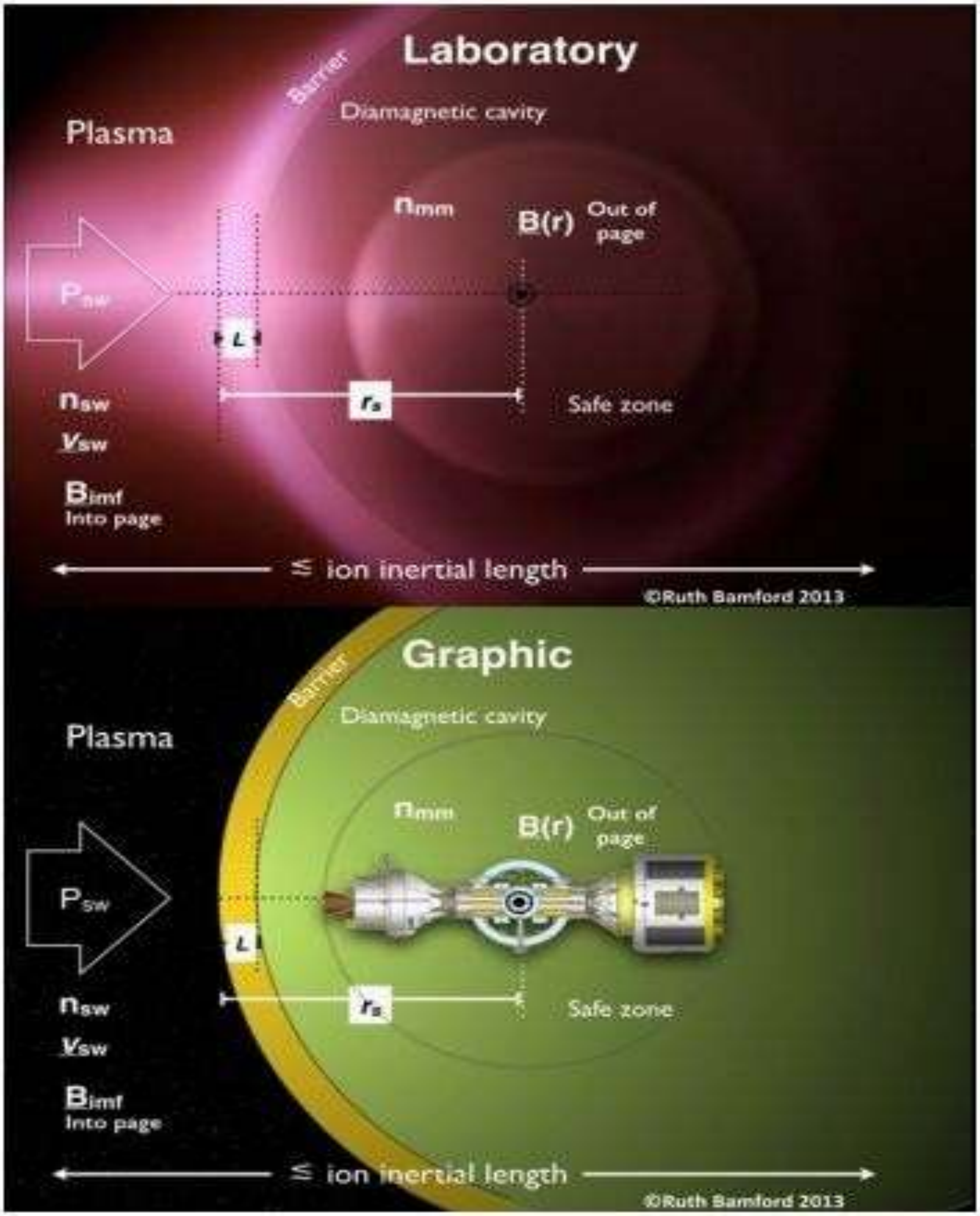


Figure 9. Magnetically kept plasma barrier generating an artificial shielding mini-magnetosphere around the space-vehicle.
Source: Bamford et al. (2014).

temperature (Giorgi and Leccese, 2013).
7. Alkaline Fuel Cells (AFC) with 250°C operating temperature (Giorgi and Leccese, 2013).
8. Phosphoric Acid Fuel Cell (PAFC) with 220°C operating temperature (Giorgi and Leccese, 2013).
9. Molten Carbonate Fuel Cell (MCFC) with 800°C

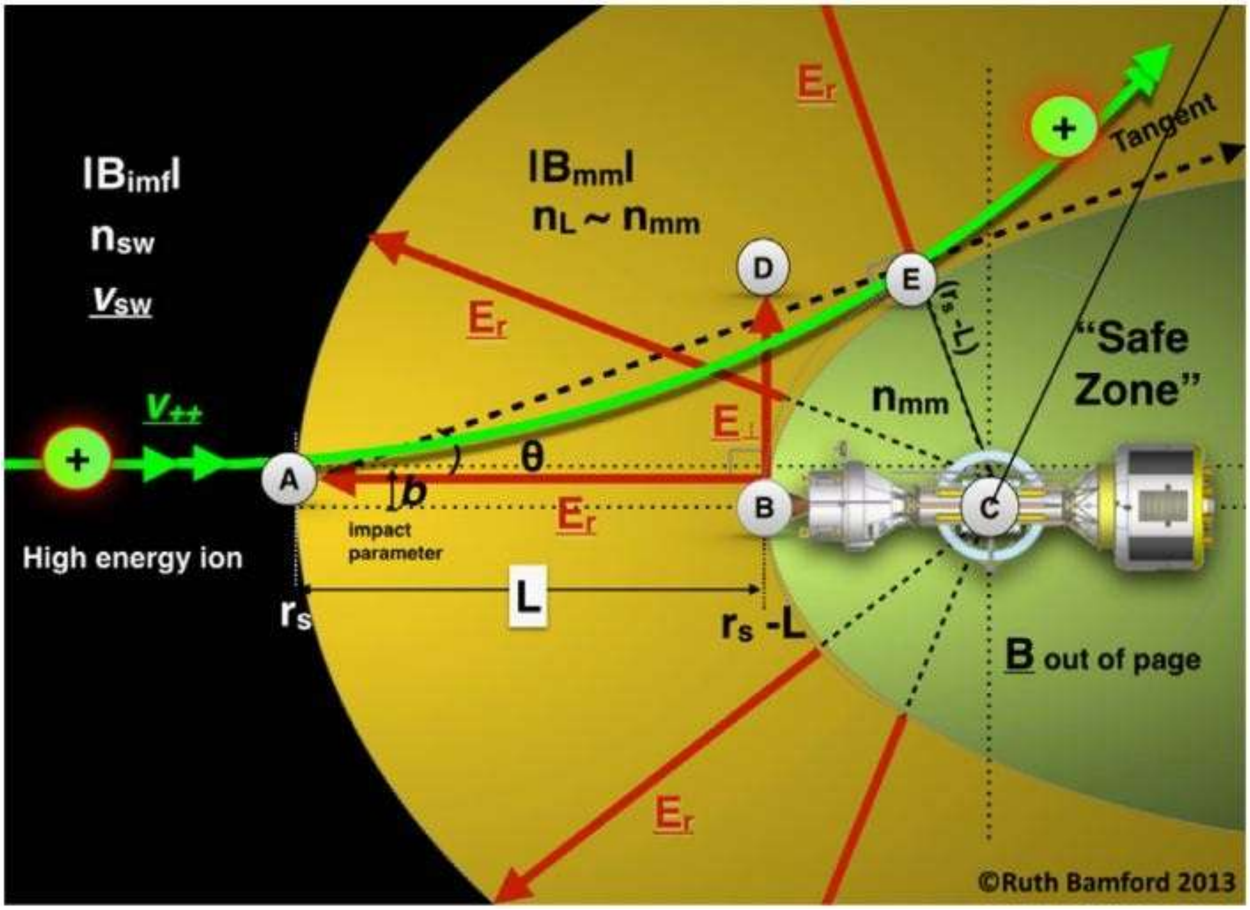


Figure 10. Plasma radiation protection system by generating an electric field around the space-vehicle and releasing ionized gas from the space-craft.
Source: Bamford et al. (2014).

operating temperature (Giorgi and Leccese, 2013).
10. Solid Oxide Fuel Cell (SOFC) with 1000°C operating temperature (Giorgi and Leccese, 2013).
11. Hydrogen-Oxygen Fuel Cell with 90°C operating temperature (Levy and French, 1968).
12. Lithium-Chlorine Fuel Cell with 650°C operating temperature (Levy and French, 1968).

With the progress in fuel cells technology, H_2/O_2 alkaline fuel cell has been produced. This fuel cell can last operative up to 2,000 h and its power-plant is 23 kg lighter when compared to Apollo's power-plant. Furthermore, it is capable of delivering power about eight times that in Apollo's mission fuel cell (Halpert et al., 1999).

Proton Exchange Membrane Fuel Cells (PEMFC) is one of the fuel cells that have been used in manned NASA space missions. However, the first fuel cell that has been used by space-crafts was Cryogenic hydrogen-oxygen fuel cell in 1965 by Gemini V space-craft. Furthermore, in Apollo's space mission, three hydrogen-oxygen fuel cells have been used (Burke, 2003).

Nevertheless, it seems that application of prototype Proton Exchange Membrane (PEM) fuel cell system for up-coming manned space missions to Mars, Titan, and beyond these planets, is promising. The reasons are the features of this type of fuel cell such as low-maintenance, low-cost, and high reliability and safety requirements for future manned space-travels (Vasquez et al., 2017).

The most recent power-supply system that can be applied in space vehicles to generate enough magnetic fields for the plasma radiation shield and Plasma Propulsion System is a new Magneto Hydrodynamic (MHD) power-plant. The aim of manufacturing of this system is the contribution to extend the human space exploration. This system is considered as an advanced, high-temperature, gas-cooled, MHD power-plant that is combined with high-power VASIMR plasma propulsion. The single-sided model of this power-plant typically operates at about 27°C (Diaz and Seedhouse, 2017).

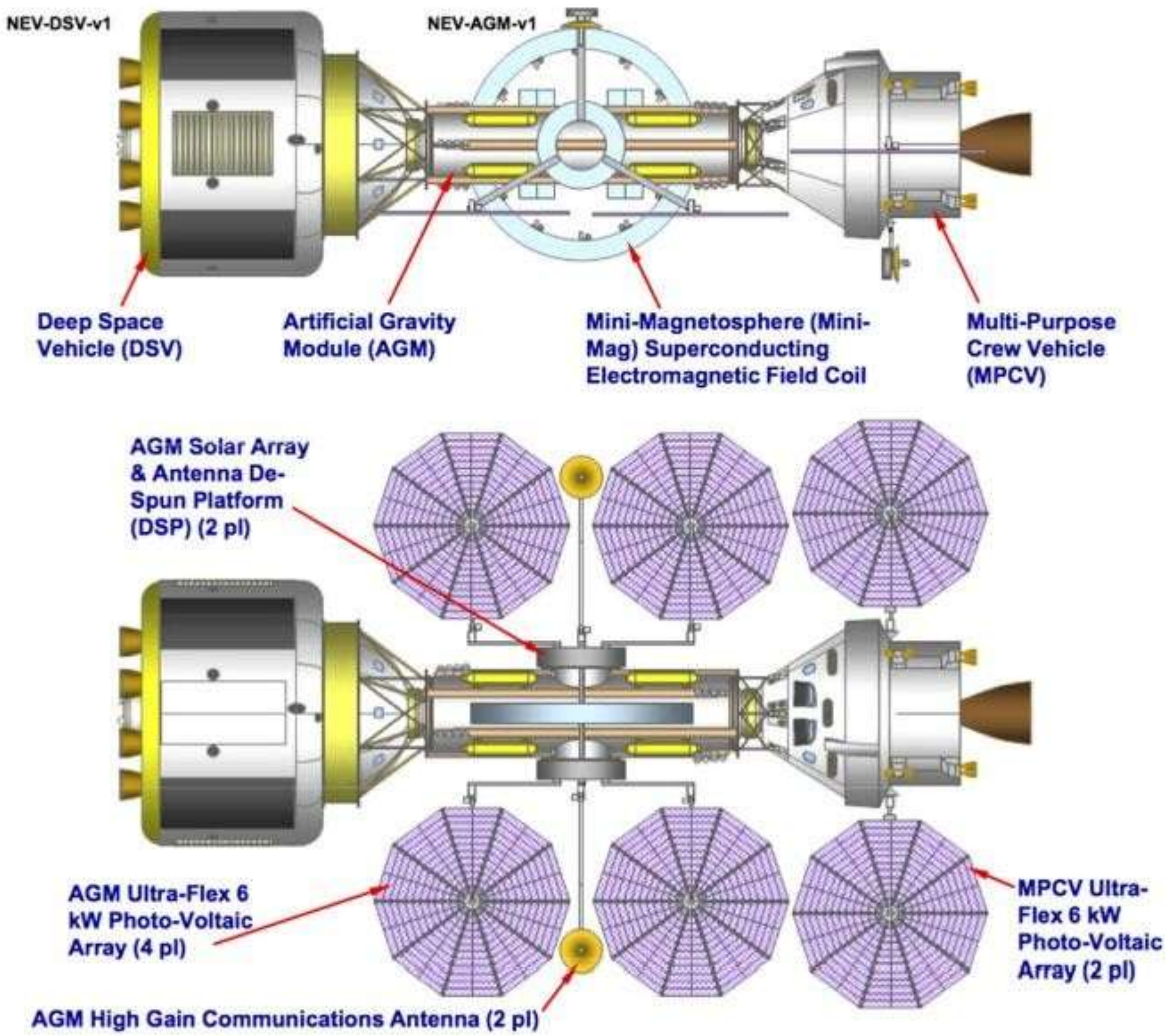


Figure 11. A conceptual design of manned interplanetary craft equipped with plasma generation system. Source: Bamford et al. (2014).

PLASMA-DEPOSITED FILMS FOR SPACE-CRAFT RADIAITON SHIELD

One of the issues that space-crafts are facing in Low Earth Orbit is the degradation of space-crafts skin by oxygen. However, in space environment other problems are also challenging and may cause degradation of space-crafts surface material as well such as thermal cycling, vacuum, radiation, debris, and micrometeoroid impacts. Hence, a suitable coating is required to shield the space-vehicle against the degradation (Zimcik et al., 1991).

The degradation and erosion process can even precipitate when the exterior surface is made of organic materials or when space-vehicle is moving with elevated velocities. At higher altitudes in geostationary orbit, Van Allen belts and solar wind have deleterious effects on organic compounds like polymers. Consequently, protective coatings such as Polymide, Kapton, and epoxy resin are applied to shield the space-vehicle against the degradation and erosion (Zimcik et al., 1991).

Deposition process of the space-vehicle coating can be performed by glow discharge at low-pressure plasma. In deposition process, microwave frequency may be applied due to obtaining higher deposition rates. Removal of organic compound is possible with applying oxygen plasma. The mass loss that resulted from organic removal can be measured using an electronic microbalance. In Tables 1 and 2 (Zimcik et al., 1991), the change in mass due to RF plasma with oxygen and microwave exposure is indicated, respectively. The third technique that can be used to measure the mass loss is

Table 1. Change in mass (µg/cm^2) after RF oxygen plasma exposure (Zimcik et al 1991).

Coating	Thickness, µm	Exposure duration			
		60 min	180 min	480 min	1440 min
SiO_2	0.7	-8.7	-11.0	-6.1	-8.8
a-Si:H	0.7	+2.2	+7.2	+25.0	+21.5
a-Si:H	1.0	-4.7	-5.0	-5.5	-2.5
a-Si:H	1.2	0.0	+9.9	+19.0	+24.1
Uncoated		-108.0	-324.0	-864.0	-2592.0

Table 2. Change in mass after microwave oxygen plasma exposure.

Sample number	Sample description (coating type)	Mass loss (mg/cm^2)
1	Control (untreated)	0.77
2	a-Si:H	0.01
3	a-Si:H	0.00
4	P-SiN	0.00
5	P-SiO_2	0.02
6	P-SiON	0.02
7	PP HMDSO	0.05

[a]O_2 flow: 200 sccm; pressure: 100 mTorr; microwave power: 300 W.
Source: Zimcik et al. (1991).

Table 3. Mass loss summary.

Simulation technique	Coating	Equivalent fluence (Atom/cm^2)	Normalized mass loss
Microwave	SiO_2	$2*10^{21}$	0.02
Plasma	a-Si:H	$2*10^{21}$	0.01
RF plasma	SiO_2	$5*10^{21}$	0.003
	a-SiO_2	$5*10^{21}$	0.009
Atomic	SiO_2	$3*10^{21}$	0.02
Oxygen beam	a-Si:H	$3*10^{20}$	0.09

Source: Zimcik et al. (1991).

the application of oxygen beam. In Table 3 (Zimcik et al., 1991), the mass loss related to the mentioned three techniques is compared. Obviously, these techniques provide very similar results (Zimcik et al., 1991).

ELECTRO-HYDRODYNAMIC AND MAGNETO-HYDRODYNAMIC PROPULSION, ALONG WITH HYDROMAGNETIC BRAKING

In Figure 12 (Goksel and Rechenberg, 2003), the pressurized helium airship with an advanced silicon carbide film structure and that works with electro hydrodynamic propulsion is shown. At the top of the vehicle, solar cells are installed. Furthermore, two superconducting magnet rings and ion engines are used in this aerospace-vehicle. This craft uses solar cells to produce electricity that ionizes the air. The ionized air can move the vehicle with speed of 80 to 160 km/h (Goksel and Rechenberg, 2003).

Silicon carbide and synthetic diamond can be the best option for generating cold emission of electrons to ionize the air. These materials can be used to develop a smart skin for the aerospace-vehicle (Goksel and Rechenberg, 2003).

In Figure 13 (Goksel and Rechenberg, 2003), an aerospace vehicle is illustrated that operates with magneto hydrodynamic propulsion. In this system, microwave is applied to heat the air in just one side of the craft. Thus, it can push it right in the direction opposite to the heated air. This propulsion system can accelerate the vehicle with even more than the speed of sound.

Figure 12. Microwave light-craft design.
Source: Goksel and Rechenberg (2003)

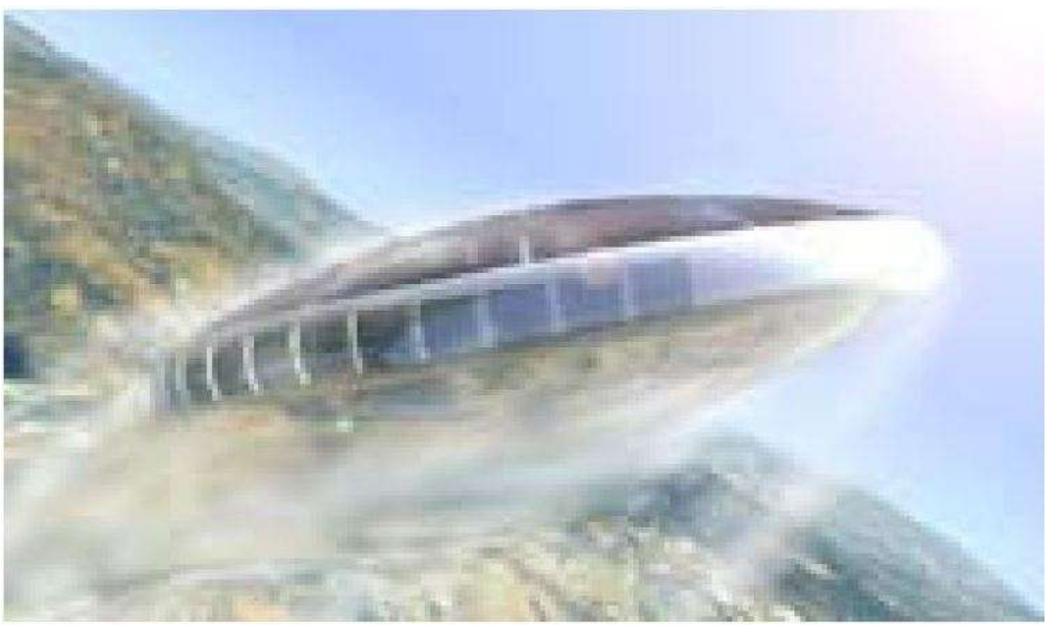


Figure 13. Trans-atmospheric craft design.
Source: Goksel and Rechenberg (2003).

Microwaves can create superhot air bubbles above the vehicle that produce an air spike which generates the nose cone that can accelerate the craft to 25 times of the sound velocity. In Figures 14 and 15 (Goksel and Rechenberg, 2003), this propulsion system is shown. No supersonic wake can be developed and water can be used to cool down the heated structure. In some applications, laser technology can be used to drive the craft as shown in Figure 16 (Goksel and Rechenberg, 2003).

Another application of plasma in aerospace-vehicles is in the hydro magnetic braking in re-entry. For developing this system, superconductive magnets which are made by silver and niobium could be applied. As illustrated in

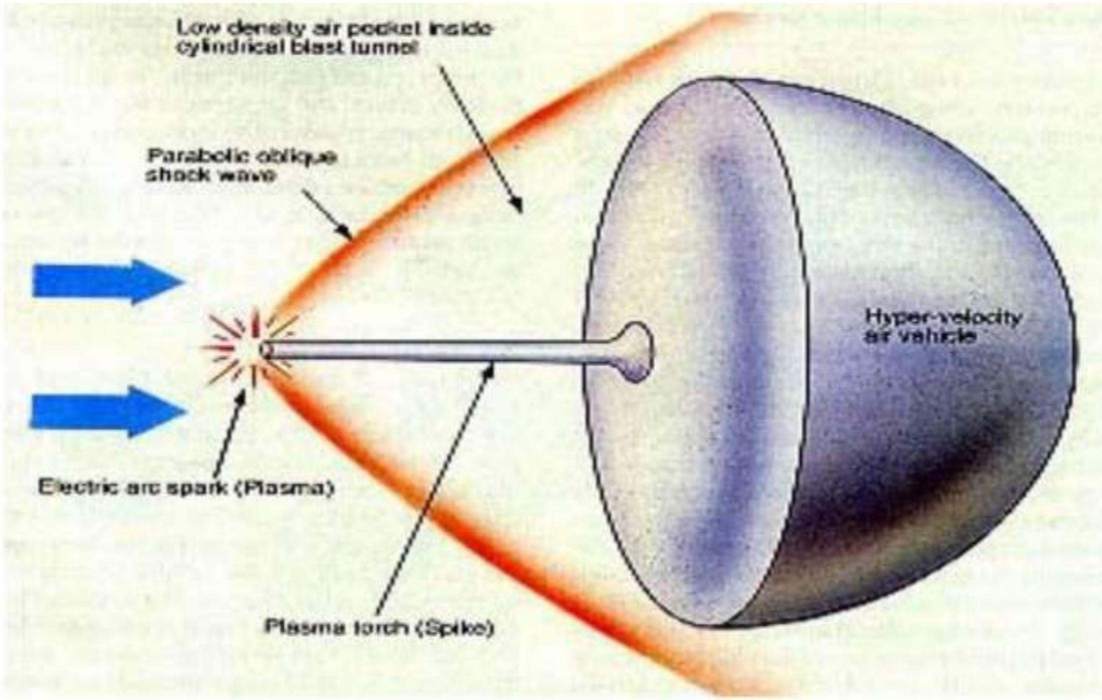


Figure 14. Principle of air plasma spike for hyper-velocity mode.
Source: Goksel and Rechenberg (2003).

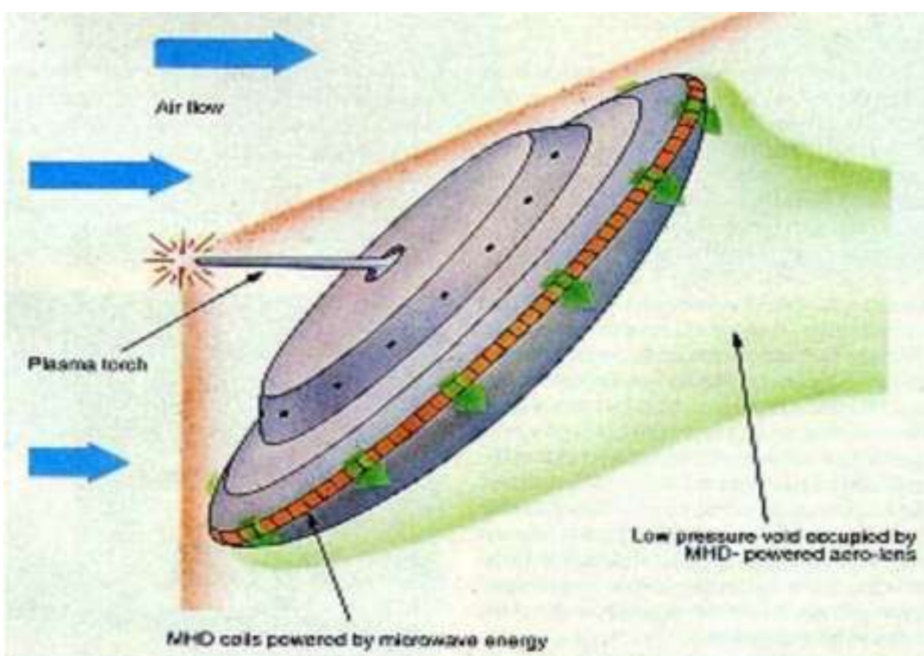


Figure 15. Principle of the magneto hydrodynamic slipstream accelerator.
Source: Goksel and Rechenberg (2003).

Figure 17 (Goksel and Rechenberg, 2003), plasma technology can be used to develop a hydro magnetic braking for space-vehicles. The function of this system is to convert the enormous kinetic energy of the space-craft

Figure 16. Light-craft flying atop a beam of laser light.
Source: Goksel and Rechenberg (2003).

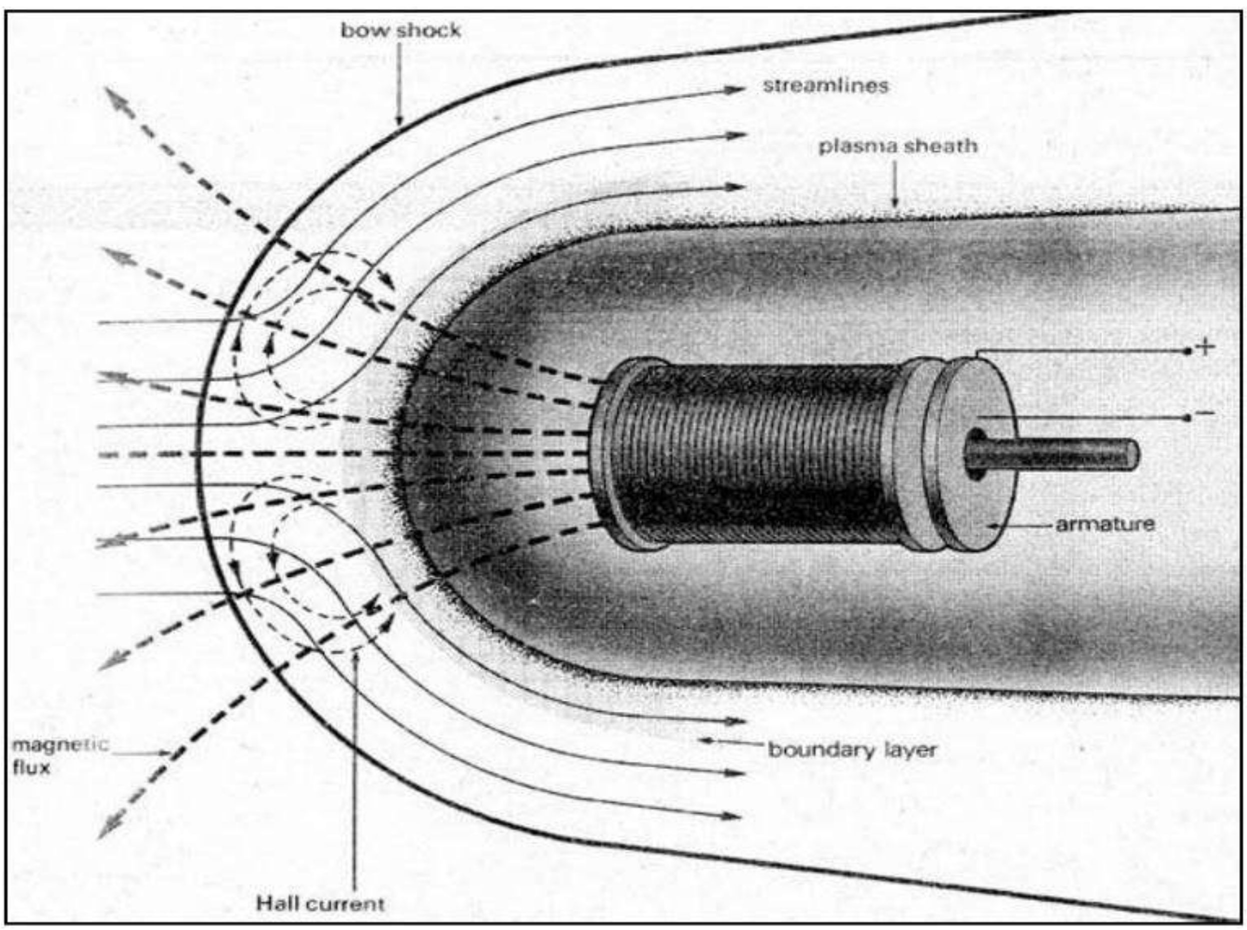


Figure 17. Principle of hydro magnetic braking.
Source: Goksel and Rechenberg (2003).

in re-entry to electricity. Hence, it avoids converting all the kinetic energy of the craft to thermal energy within re-entry. The electricity produced by this system can be used in space-craft. Additionally, by decreasing the space-vehicle temperature in re-entry, it creates a safer re-entry for the crew and the space-vehicle (Goksel and Rechenberg, 2003).

DISCUSSION

For application of plasma technology in aerospace-vehicles, it seems that at least a few factors are necessary for consideration. First, it appears that experimental procedures are required to be conducted in the lab to verify the range at which the plasma technology is applicable in aerospace-vehicles. It can help to understand how effective application of plasma technology can be for radiation shielding, propulsion system, etc. Second, financial assessment seems necessary to find out the price at which the application of plasma technology is feasible for applying in aerospace-vehicles. Consideration of this issue is also of high significance due to the reason that cost-effectiveness is always an important matter in engineering design and production.

CONCLUSIONS

1) The influence of GCRs and SPEs radiation on astronauts' health during manned-space missions is required to be considered significantly to prevent the crew illness with prevention methods.
2) According to the results obtained by this research, it appears that plasma radiation shield is very promising to create a safe space-craft for astronauts in future manned-space missions in terms of avoiding the hazardous effects of radiation.
3) The effect of magnet power supply operating temperature on space-craft materials should be thermally analyzed to ensure the safe and reliable space-vehicle structure and prevent the thermal failure of space structure.
4) For appropriate design and operation of plasma radiation shield, many factors must be considered precisely such as adequate magnetic field for generating required electron cloud, weight of the magnet system and its effect on the space-vehicle integrity, etc.
5) To prevent the erosion and degradation of space-vehicle skin due to oxygen in Low Earth Orbit, coatings such as ceramic, aluminum, polymide, and epoxy can be deposited with plasma on space-craft skin with glow discharge at low-pressure.
6) The plasma propulsion systems such as electro hydrodynamic and magneto hydrodynamic can be applied to accelerate the craft up to 25 times of the sound velocity.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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