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Nuclear powered air-breathing electric thrusters used in UAVs for extra-terrestrial applications

Abstract

With an interest in space exploration developing at a remarkable rate in the course of the most recent couple of years, it has become a daunting task to explore the different planets because of hostile environmental conditions present on them and here UAVs play a critical role. This paper aims to study and develop Unmanned Aerial Vehicles that run using motors & electric thrusters and uses nuclear fuel Plutonium-238 (238Pu) as its power generation source. The UAV being ideated plans to operate both in earth's atmosphere and extra-terrestrial space. The heat from the decay of 238Pu is extracted by using Multi Mission Radio Thermoelectric Generator (MMRTGs) using thermocouples thus providing electricity. The idea of utilizing MMRTG in UAVs has been proposed as it works well in both the space vacuum and the planetary atmosphere. The heat energy from the MMRTG can be utilized as a consistent wellspring to keep up with appropriate working temperatures for a UAV and its instruments in cold environmental conditions. MMRTG acts as a main power source for the UAV. The air-breathing electric thrusters work by compressing the air molecules into plasma and accelerating the stream of plasma molecules to provide thrust for the satellite, thus can be very well utilized in vacuum of space for continuously providing thrust for the operation of the UAV in low-earth orbits. The thrusters are connected to a propeller, as in atmospheric conditions, air-breathing electric thrusters require a continuous flow of air to generate thrust. This paper concludes the working of the propulsion system for UAVs in various environmental conditions and depicts the advantageous uses of MMRTGs & Air-breathing electric thrusters in UAVs for extra-terrestrial space transportation and extends its research for future profound space investigation.

Keywords: UAVs, MMRTGs, Space, Air-breathing, Electric Thrusters

Contents

List Of Figures

1. Introduction

To explore space, it has always been a dream of humankind and with the advancements in technology across the world, it has forced the countries to participate in the space race competeing against one another, developing better and advanced technologies to peek in the outer space. With all this happening around, extra-terrestrial UAVs are also been developed for space exploration missions. These UAVs require a very sturdy and consistent power source throughout their journey to be successfully able to complete their mission objective.
This paper discusses the development of an innovative engine that uses Nuclear Fuel to run the Electric air-breathing thrusters to generate thrust. This engine can be used in all terrain conditions, in VLEO & LEO orbits, in lower dense atmospheres as well as in higher dense atmospheres. The engine developed does not use any propellant for the generation of lift hence increasing the life cycles and overall mission timeline. It also generates a negligible amount of carbon footprints, is quite efficient and also does not harm the environment.
Previous researches have been done on use of MMRTG as a power source in space missions. With the knowledge of existing usage of MMRTGs, this paper mainly deals with how effectively the energy from nuclear fuel could be used in unmanned vehicles planning for space missions. It also discusses about use of air breathing electric thrusters which is currently under design phase, with how combination it can be combined with MMRTGs and be effectively used as a propulsion unit for the unmanned vehicles.

2. MMRTG

Radioisotope Thermoelectric Generators (RTGs) are nuclear spacecraft power systems been developed to generate electricity and power spacecrafts in various missions. They provide electrical power using heat from the natural radioactive decay of plutonium-238, in the form of plutonium dioxide. Multi Mission Radioisotope Thermoelectric Generators (MMRTG) is a type of Radioisotope Thermoelectric Generators been developed to be used in space missions and deep space explorations.

2.1 Drawing

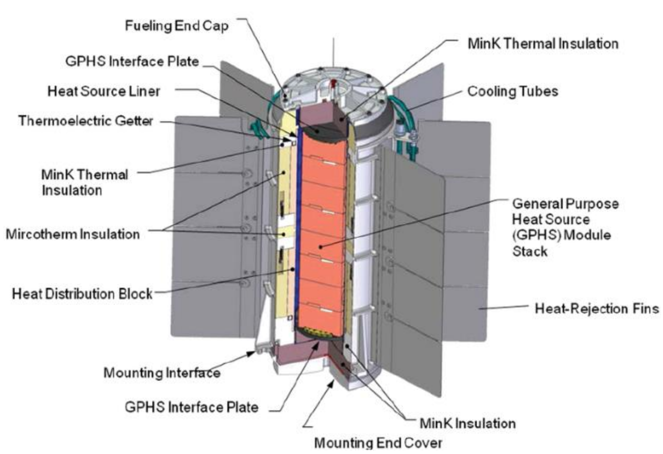

Figure 1 : MMRTG

The nuclear power system which has been talked about here is used to supply electricity, and use excess heat being developed for a variety of space exploration missions. The Multi Mission Radioisotope Thermoelectric Generator (MMRTG), which has already been designed, is added with electric thrusters to make it operate on planetary bodies with atmospheres as well as in the vacuum of space. An MMRTG generates about 110 watts of electrical power at launch, with the use of electric thrusters, there can be an increment of thrust with time that can be utilized with a variety of potential mission requirements.

2.2 Nuclear Fuel

The Nuclear fuel used in our study is Plutonium-238 (^{238}Pu), it's an already tried and tested source of nuclear fuel used on spacecrafts for long.
There are certain criteria for which a nuclear fuel is chosen:

(i) Exist in an insoluble form otherwise won't be readily absorbed into the body in the unlikely event of a launch accident.
(ii) To have relatively low neutron, beta and gamma radiation emissions, so as to not adversely affect spacecraft instruments or require excessively massive shielding.
(iii) Be stable at high temperatures, so its characteristics remain essentially unchanged over many years.
(iv) Have a long enough half-life (at least 15 to 100 years), so that it can generate for many years sufficient heat for transformation into electricity.
(v) Have a high-power density, so a small amount of it can generate a substantial amount of heat.

Pu-238 has a half-life of 87.7 years, making it a much longer-lasting source of energy than other plutonium isotopes. They exhibit high heat density and emits primarily alpha particles, which are easily shielded, this makes it safer to handle than most other radioactive materials. High heat density and low shielding requirements both make for a lighter device and also can be easily used incorporated in the nuclear batteries, and thus been chosen to be used as a nuclear fuel here.

2.3 Production of Plutonium-238 (^{238}Pu)

In Nuclear reactors, Uranium-235 (U-235) and Uranium-238 (U-238) are used. Here, using U-235 as a fuel, it releases neutrons which struck U-238, irradiating it and converting some of it to U-239. The U-239 then decays into two steps, first turning up into Neptunium-237, which transforms slowly into Neptunium-238, that can be recovered from research reactor fuel or special targets and this later decays into Plutonium-238 (Pu-238).

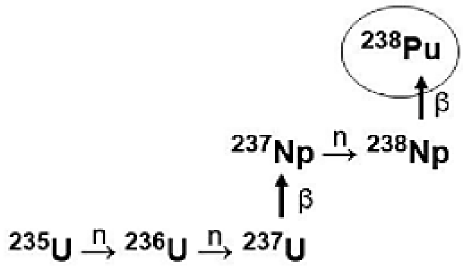

Figure 2 : Production of Plutonium-238

2.4 Working of Plutonium-238 (^{238}Pu) as a Nuclear Fuel

The plutonium-powered RTG is a 290-watt system called the general-purpose heat source (GPHS) RTG. The thermal power for this system is formed of 18 GPHS units. Each GPHS unit contains 4 iridium-clad ceramic Pu-238 fuel pellets, which is about 5 cm tall, 10 cm square in area each and weighs around 1.44 kg. The multi-mission RTG (MMRTG) uses 8 such GPHS units with a total of 4.8 kg of plutonium oxide (^{238}Pu). It can produce around 2 kW of thermal energy which can be used to generate about 110 watts of electric power, 2.7 kWh/day.

Electrical Power is generated using the heat produced from the natural radioactive decay of the Plutonium-238 fuel. The large difference in temperature between this hot fuel and the cold environment of space is applied across special solid-state metallic junctions called thermocouples, which generates an electrical current using no moving parts. The MMRTG design incorporates PbTe/TAGS thermoelectric couples where TAGS stands for the thermocouple been developed incorporating tellurium (Te), silver (Ag), germanium (Ge) and antimony (Sb).

However, there is a limitation in the use of Plutonium-238, since it is manufactured isotope, there is difficulty in producing it in large quantities.

2.5 Working of MMRTG

A radioisotope thermoelectric generator changes over heat into power with no moving parts by using the thermoelectric effect. Holding two different electrically conductive materials at various temperatures and joining them along in a closed circuit generates current. A pair of conductive materials used in this manner is known as a thermocouple. A thermocouple has a ‘hot shoe’ and a ‘chilly shoe.’ Here, the decaying plutonium warms up the hot shoes of the thermocouples while the fins (blades) present at outside spreading out into the outside space gets cooled by the temperature out there.

The plutonium dioxide ceramic (fuel pellet case) is split into 32 pellets, each weighing 150 grams. Each pellet is clad in iridium. The iridium cladding is a safety feature that blocks the alpha particles emitted by the plutonium pellets. It also has a high melting temperature (around 2400°C), in case the cooling framework fizzles out.

To divert the heat from the MMRTG core into power, the developed hot core is encased in a graphite heat conveyance block. Then, comes a layer of thermoelectric modules, their hot shoes in contact with the hotness dissemination block and the cold shoes contacting the external shell of the MMRTG and its heat-radiating fins. The hot shoes work at a temperature of 520°C, the cold shoes work at various temperature relying on the outer space temperature. The thermocouple thus converts the heat into power (electricity) and it pumps up the system.

Figure 4 : MMRTG Structure

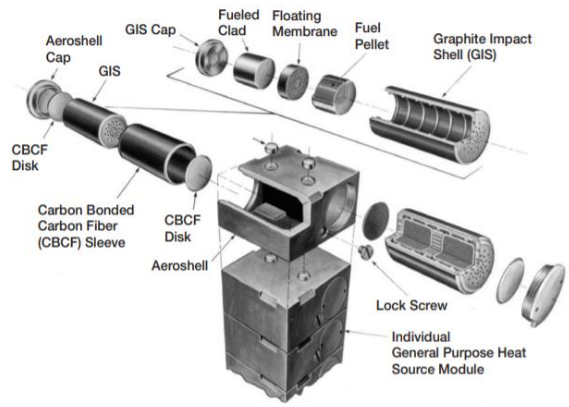

Figure 3 : Components of MMRTG

2.6 Safety-Design of MMRTG

Several layers of safety features present in an MMRTG helps to minimize the release and dispersal of nuclear material under a wide range of possible accident conditions. They have been carefully designed, intended to endure a sendoff mishap, similar to a launch pad explosion or a midair separation, without delivering radioactive material into earth's environment or seas. Here, two pellets go inside a graphite impact shell and a carbon-forced carbon-fiber sleeve encasing the impact shell. Two such sleeves are inside each general-purpose heat source module. The center of the MMRTG is a stack of eight of these modules, and the core is encircled by an aluminum alloy lodging. In case of a sendoff mishap at high altitude, the aluminum lodging would dissolve, which would disperse away the eight modules. Those lower-mass modules would have lower terminal velocities than the entire MMRTG. At their lower speeds, the carbon fiber aeroshells wouldn't melt upon reemergence. Regardless of whether the pellets are exposed to enough forces to break them, their ceramic structure is so made that will break into large chunks rather than forming into dust which could be breathed in. Thus, the MMRTG system is so well developed to prevent any possible catastrophe to happen during unexpected conditions.

3. Thrusters

Developments of rockets and the advancement of technology helped space organizations to reach distance points and, in these missions, made use of the various propulsive devices to attain particular orbit or reach particular destinations in space, one such propulsive device is Thrusters which has been a significant device in generating the thrust required for the spacecraft to move outside the earth.

There are several thrusters that have been used for space applications:

- Rocket Engine: This class of thrusters provides thrust by burning the propellants and expelling the burnt gas that would generate the thrust based on the change in velocity and the mass flow rate.

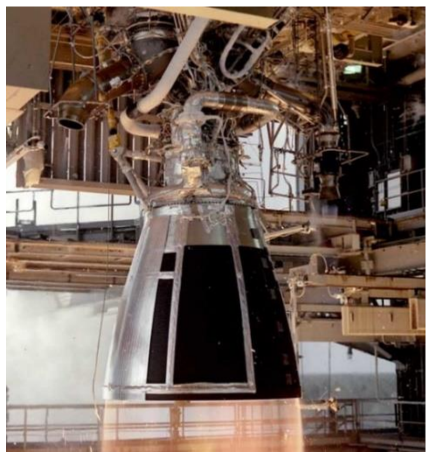

Figure 5 : Rocket Engine

- Electrohydrodynamic thruster: Thrust force is generated through the corona discharge in the rarefied atmosphere.

- Electrostatic ion thruster: This thruster works on the principle of ionizing the propellants and the ionized propellants are accelerated in the electric field and the discharged high-speed ions would enable to generate the required thrust.

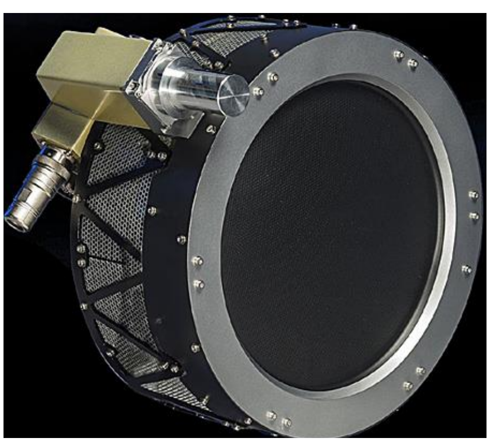

Figure 6 : Ion Thruster

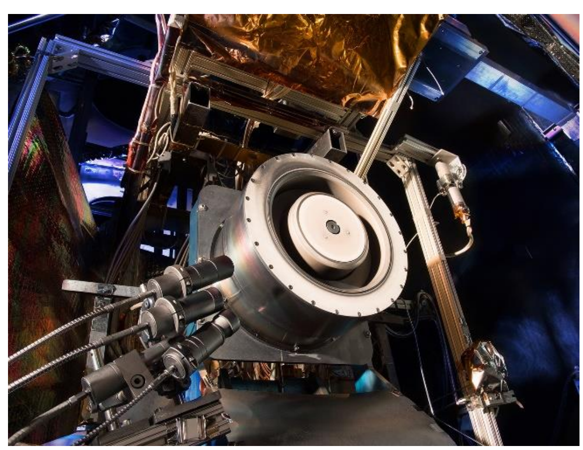

Figure 7 : Hall Effect Thruster

- Hall-effect thruster: It uses electrostatic potential to accelerate the ions to very high speed hence generating thrust. Propellants such as xenon is fed into the anode and this neutral xenon diffuse into channels of thrusters, then it is ionized by collision by circulating it at very high speeds then these ions are accelerated with electric field between the electrodes and high energized ion is expelled producing huge amount of thrust.
- Pulsed plasma thruster: It consists of two electrodes located closed to solid propellent; a capacitor placed is charged to high voltage from the power source. The igniter placed near the propellent produces spark which discharges electrostatic unit of charge to generate plasma, the surface of propellent is now ionized to form plasma propellent. Using Lorentz force plasma is accelerated and is propelled forward hence providing energy.

- Magneto plasma dynamic thrusters: It is a form of electrically powered spacecraft propulsion which uses the Lorentz force to generate thrust. A gaseous material is ionized and fed into an acceleration chamber, where the magnetic and electric fields are created using a power source. The particles are then propelled by the Lorentz force resulting from the interaction between the current flowing through the plasma and the magnetic field out through the exhaust chamber.

3.1 Use of Plasma Propulsion

Plasma engines have a much higher specific impulse (I_{sp}) value than most other types of rocket technology. Their theory of operation is relatively simple and can use a variety of gases, or combinations. These qualities suggest that plasma thrusters have value for many mission profiles. plasma thrusters are capable of reaching relatively high speeds over extended periods of acceleration and can be used for smaller systems.

3.2 Air breathing plasma

Air breathing plasma thrusters are composed of intake and electric thrusters, the rarefied gas which causes drag in LEO orbits are taken as propellants. Intake is designed such that gas molecules are collected and directed to the thrusters. The molecule is then ionized by the thrusters and expelled from the acceleration stage at very high velocity generating thrust, power can be supplied through any power sources, this technology can be used in any planet with any atmosphere provided the thrusters can process the propellant.

3.2.1 Working

An ABEP is composed by an intake and an electric thruster, rarefied gases which are used as the propellant. An intake will be used to collect the gas molecules and direct them to the thruster. The particles will then, at that point, be ionized by the engine and expelled from the acceleration stage at an extremely high speed, generating thrust. The electric power required can be provided by similar power subsystems developed for electric propulsion systems, using a combination of solar arrays and batteries, however other sort of electric power subsystems can be considered. An ABEP could increase the lifetime of satellites in LEO and VLEO by compensating the atmospheric drag during their time of operation. This technology could likewise be used on any planet with atmosphere, on the off chance that the thruster can process other propellants, and assuming that the power source can give the required power.

By utilizing the atmospheric particles which are liable for the generation of drag as propellant, air-breathing electric propulsion could allow thrust generation in low orbits without the need or help of any on-board propellant. In this manner, it becomes feasible to eliminate a significant share of spacecraft mass and so it will help in increasing the lifetime of the mission. Due to good engaging quality of air-breathing electric propulsion, and the easy practicality of using atmospheric gas as propellant for Electric Propulsion engines has been very much explored by numerous researchers across the world.

3.2.2 Drawing

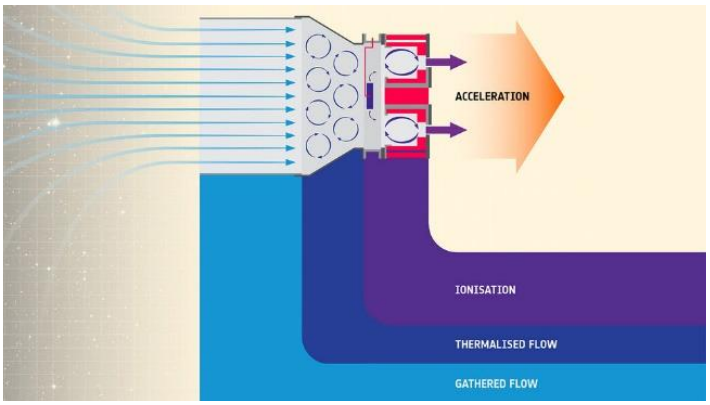

Figure 8 : Drawing for Air Breathing Electric Propulsion

4. Overall Working of Nuclear-powered Air-Breathing Unit combined

Taking all these components together, a new propulsion system can be devised. The system developed is for the usage in space travel vehicles for interplanetary missions. All the three components – MMRTG, Air-breathing Engines & Thrusters are together used in combination to produce the required thrust and propel the vehicles in space.

Multi Mission Radioisotope Thermoelectric Generators (MMRTG) is a type of Radioisotope Thermoelectric Generator which uses nuclear fuel to generate electricity. Here, Plutonium-238 (^{238}Pu) is used as a nuclear fuel which by decaying warms up the hot section of the thermocouples while the blades present at outside spreading out into the outer space and gets cooled by the temperature out there. Thus, using an array of thermocouples, the heat released by the decay of the Plutonium and the cold temperature present owing to the temperature in outside space, electricity is generated. This whole process is governed by the Seebeck Effect. The power is thus generated using the MMRTG. In the Air breathing electric propulsion part, there is an air intake where in the air current is introduced in the chamber and an air ioniser present is used to ionise (electrically charge) air molecules. The ionization process is done with the help of voltage or the power which has been produced by the MMRTG. Now, these ionized air molecules are passed down to the thruster, and are expelled from the at very high velocity generating thrust, the power required for the process is supplied by the electricity generated by the MMRTG earlier. Thus, covering these three processes it accounts for the propulsion system, which develops enough amount of thrust ensuring the vehicle is propelled in the outer space and also eases its travel life in LEO conditions.

Figure 9 : Combined Propulsion Working Unit

5. Conclusion

Unmanned Aerial Vehicles have got many applications and use of UAV for extra-terrestrial applications would be very beneficial for space exploration. Considering the advantages of nuclear power as an energy source, it has been incorporated in the propulsion system unit, combining it with air-breathing electric thrusters will impart a larger thrust to the UAVs and thus will help in propelling it in outer space. Thus, the UAVs can be used for near space applications in VLEO & LEO for longer durations.

This concept on the development of Air-breathing electric thrusters has a huge future scope, with the advancement in technology this concept can be further developed to be used for space tourism and many other space explorations.

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