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# Conceptual Design of Ion Thruster for Aviation Applications

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**ABSTRACT:**The emerging “new space” age strengthens the importance of rapid development and qualification procedures of electric engines and their peripheral devices. A key element is the reliable simulation of the thrusters and their supply units on short time scales. Global models seem to be well suited for this purpose. An ion thruster, ion drive, or ion engine is a form of electric propulsion used for spacecraft propulsion. It creates thrust by accelerating ions using electricity. In this paper we are presented, ion thrusters used in aviation application with the example of RF Thrusters and regular plane. Structural features and design parameters are obtained by scaling performances of smaller RF ion thrusters developed. The thruster’s structure consists of the gas-discharge chamber made of alumina, and equipped by high-voltage unit for xenon feeding, inductor and RF generator.

**KEYWORDS:**Aviation, Ion Thruster, Propulsion configuration, Parameters

## I. INTRODUCTION

An ion thruster is a form of electric propulsion used for spacecraft propulsion that creates thrust by accelerating ions. The term is strictly used to refer to gridded electrostatic ion thrusters, but may often more loosely be applied to all electric propulsion systems that accelerate plasma, since plasma consists of ions. Ion thrusters are categorized by how they accelerate the ions, using either electrostatic or electromagnetic force. Electrostatic ion thrusters use the Coulomb force and accelerate the ions in the direction of the electric field. Electromagnetic ion thrusters use the Lorentz force to accelerate the ions. In either case, when an ion passes through an electrostatic grid engine, the potential difference of the electric field converts to the ion’s kinetic energy. Ion thrusters have an input power spanning 1-7 kilowatts, exhaust velocity 20-50 kilometres per second, thrust 20-250 milli newtons and efficiency 60-80%.

They (ion thrusters) well known for little propellant, comparatively to other forms of propulsion, and thus can travel great distances. Ion thrusters, and other electric propulsions, are also easier to launch. The reason is because they have fewer launches mass due to reduced propellant. They are cheaper to launch and often used on small spacecraft for long range missions. As name suggests, “An ion thruster ionizes propellant by adding or removing electrons to produce ions”. Most ion thrusters use electron bombardment. This is when a high energy electron (negative charge) is collided with a propellant atom (neutral charge). This releases electrons from the atom and creates a positively charged atom. The gas produced is made up of positively charged ions and negatively charged electrons, which results in no overall electric charge. If you hadn’t guessed, this is plasma and plasma can be affected by magnetic and electrical fields.

## II. LITERATURE REVIEW

F. Cichocki et.al. (2017) investigated that the ion beam shepherd is an innovative contactless technique for space debris removal, in which an impulse transfer thruster pushes the debris object through the action of a plasma plume and an impulse compensation thruster maintains formation flying. A detailed description of the physical phenomena taking place in a plasma plume expansion into vacuum is provided [1, 2].

With the use of dedicated thruster performance models, complemented with simplified plume expansion and plasma-debris interaction models, a system-level optimization study of the impulse transfer thruster alone and of the overall electric propulsion subsystem is presented for an ion beam shepherd mission example. The increasing number of space

debris objects that populate certain types of orbits (especially the Sun synchronous low Earth orbits and the geostationary orbits) can potentially threaten their exploitation in a relatively close future and, therefore, demands an international effort in two major fields: mitigation strategies and active debris removal/relocation. We have to put efforts into investigating and demonstrating the technical feasibility of active debris removal (ADR) techniques, which are necessary to effectively stop the growth of the space debris population. Among all techniques of ADR, the ion beam Shepard is efficient technique [3].

### III. METHODOLOGY

#### Design Analysis

The basic design corresponds to other RF ion thrusters, and scaling laws have been applied (see below). The engine consists of two main components, namely the ionizer and the grid system that are clamped together. The ionizing system consists of the propellant injector (GI) and the discharge vessel with the RF-coil (RFC) surrounding it. The propellant injector is inserted tightly in a tube of the ionizer vessel placed on the axis. It includes a high-voltage isolator and several narrow channels to inject Xenon jets radial into the discharge plasma.

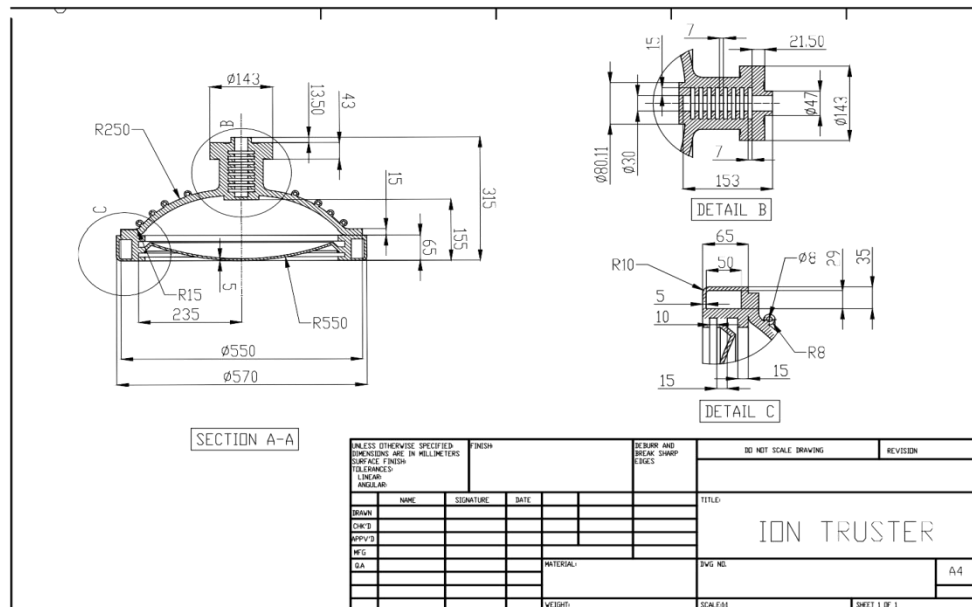


Fig. 1 Schematic cross-section ion thruster

The ionizer vessel is made of Alumina and has a special bended shape to withstand the mechanical load at launch and to minimize the inner wall surface, i.e., the wall recombination losses of the plasma ions. Following an empirical scaling law 6, the discharge vessel has an optimal length of 15.5 cm. The RF-coil is made of a copper tube, has 9 turns, and is tightly wound around the ionizer. The grid system consists of a 0.5mm thin screen grid system (SG) (or “emission grid”) made of Invar, a 2.7mm thick accel grid (AG) of graphite, and 2.5mm thick decel ring (DR) of stainless steel which serves as outer wrap of the entire accelerator system, too. Macor is used for grids isolating. The grid system has been designed and optimized for 4.5 kV of positive high voltage (PHV) and about 500 V of negative high voltage (NHV).

#### Scheduled Power and Thrusting Data

In view of the envisaged power consumption of 35 kW of each thruster (including PPU), we chose as the beam current  $J_b=7.00$  A. Then, the beam power (for 4.5 kV of PHV plus the plasma potential of about  $V_p=25$  V) would be 31.68 kW. Counting with an open area of the 1st grid of 1009 cm<sup>2</sup>, we get as the extracted ion current density  $j_i=6.94$  mA/cm<sup>2</sup>. This means that the engine will be throttled for lifetime reasons (see below) and that it may be thrust enhanced by a factor of 1.68 to run with 11.66 mA/cm<sup>2</sup> (like RIT-22 at 175 mN of thrust).

### Scheduled Propellant Data

The Xenon gas flow needed for 7.00 A of beam current amounts to 97.55 sccm or 9.526 mg/s, respectively. The discharge pressure of the 46.5cm RF-thruster has been estimated by using the RIT scaling laws. With an uncertainty of some percent, we assume  $p_d = 1.25 \cdot 10^{-4}$  Torr.

### Physical Verification of the Assessments

The scheduled data, mentioned above, derived from basic equations and the application of scaling laws gained by testing Giessen's and Astrium's RIT engines with 2.5 cm, 4 cm, 10 cm, 15 cm, 22 cm, 26 cm, and 35 cm of ionizer diameter. In general, the RF-power is needed to compensate three power loss mechanisms: On one hand, the discharge must be sustained, i.e., the propellant must be permanently ionized. Together with other inelastic collisions like light excitation we may count the "volume losses" roughly with 25 eV per generated ion. Comparing the 1009 cm<sup>2</sup> of open grid area with the entire surface of the ionizer of 4175 cm<sup>2</sup>, a total ion current of 29.8 A must be produced, requiring about 745 W. In the equilibrium, this total current will disappear from the plasma, partly by extraction and beam formation, partly by recombination at the ionizer wall. An ambipolar current is driven to the wall by a plasma potential  $V_p$  which amounts to 26.4 V at 5 eV of electron temperature (being typical for RFthrusters). Thus, we get "wall losses" of about 787 W. Finally, we have to add non-plasma losses (dielectric losses in the alumina vessel, eddy current losses in the first grid and the thruster case, Ohm's losses in the RF-coil, etc.). These losses are hard to quantify, but the envisaged 2100 W of RF-generator power (less two plasma loss mechanisms), i.e., 568 W seems to be more than sufficient to cover all non-plasma losses. Our second check refers to the named 6.94 mA/cm<sup>2</sup> of ion current density. It is limited on one hand by the plasma yield, i.e., the plasma density  $n$  and the electron temperature  $T_e$ , and on the other hand by Langmuir Schottky-Child's law, i.e., by the extraction voltage  $U_{ex}$  and the acceleration length  $d$ .

### Lifetime Assessment

It is known that the lifetime of an RF ion engine is only limited by the sputtering of the accel grid by those charge-exchanged ions which reach and impact this electrode. The end of lifetime happens when spaces between beamlet borings break.

### Reinforced Operation

We mentioned already that the RF IT has been designed to operate in a throttled mode in order to guarantee the demanded long lifetime. However, it may be interesting to ask for enlarged thrusting data, too. When reinforcing by a factor we get the maximum beam current density at the entrance of the grid system which could be extracted with 5.0 kV of voltage.

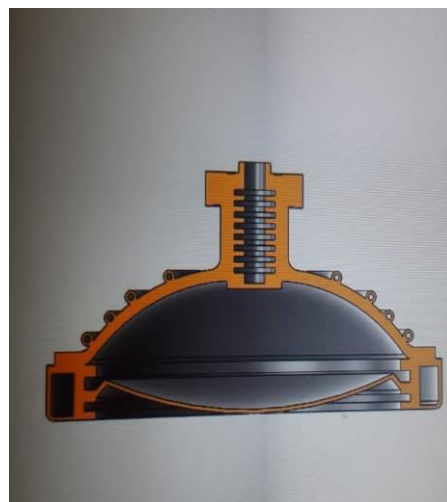


Fig. 2 Ion Thruster



The ion thruster is a type of electric propulsion applied for spacecraft missions like orbit transfer, orbit lifting, station keeping or interplanetary navigation. Ion thrusters feature very high specific impulse (from 2000 to over 10,000 s) and efficiency (from 60% to over 80%) compared to the commonly used electric thrusters such as Hall thrusters.

In addition to the excellent performance of ion thrusters, effects from ion thruster plume have long raised concerns such as interference torque, sputter erosion of surface materials and deposition of eroded thruster materials onto sensitive parts of the spacecraft. In most ion thrusters, electrons are generated with the discharge hollow cathode by a process called thermionic emission (Dunbar). These electrons are attracted to the discharge chamber walls, which are charged to a high positive potential by voltage applied by the thruster's discharge power supply. The propellant atom is then injected into the discharge chamber for electron bombardment. High strength magnets prevent electrons from reaching the discharge walls too easily, increasing the amount of time they are in the chamber and increasing to probability to ionization.

The positively charged ions migrate toward grids that contain thousands of very precisely aligned holes (apertures) at the aft end of the ion thruster. The first grid is positively charged electrode (screen grid) (Dunbar). A very high positive voltage is applied to the screen grid, but it is configured to force the discharge plasma to reside at a high voltage. As ions pass between the grids, they are accelerated toward a negatively charged electrode (the accelerator grid) to very high speeds up to 90, 00 mph.

The positive ions to be accelerated out of the thruster as an ion beam. Thrust is achieved! Electrons are also released from the neutralizer, another hollow cathode, to make the beam neutral. It prevents ions from being drawn back to the spacecraft. Ions being drawn back would reduce thrust and erode the spacecraft, which is bad. The most commonly used propellant in ion propulsion is xenon. This is for a few reasons as follows: High atomic mass and is easily ionized, thus creating a desirable amount of thrust. Inert and has high storage density, which makes great for storing on spacecraft. Ion thrusters have an input power need of 1-7 kW, exhaust velocity 20-50 km/s, thrust 25-250 milli newtons and efficiency 65-80%.

#### IV. TYPES OF ION THRUSTERS

##### **Electrostatic Ion Thruster**

This type of thruster is commonly use xenon gas which has no charge and it is ionized by bombarding with energetic electrons. These electrons are provided from hot cathode filament and accelerated into electric field of cathode fall to anode. The electrons can be accelerated by the oscillating electric field induced by an alternating magnetic field of a coil which results in a self-sustaining discharge and omits any cathode. The positive ions can extract after bombarding of electrons with xenon atoms, and these ions are accelerated by electrostatic force.

##### **Electromagnetic Ion Thruster**

Electromagnetic thrusters use the Lorentz Force to accelerate all species (free electrons as well as positive and negative ions) in the same direction whatever their electric charge, and are specifically referred to as plasma propulsion engines, where the electric field is not in the direction of the acceleration.

##### **An Example of Regular Plane**

A number of thin electrodes run across the plane wings, while the back of the plane has a curved surface, called an aerofoil, to produce the lift that happens in a regular plane wing. There are also thin wires at the front of the plane, which as charged to positive 20,000 volts. The aerofoil at the back is charged to negative 20,000 volts, creating a strong electric field. As for how the plane works, at the front of the plane, electrons are removed from nitrogen molecules in the air to produce ions. These are then accelerated towards the back, creating an ionic wind as they go which gives the plane thrust to move through the air.

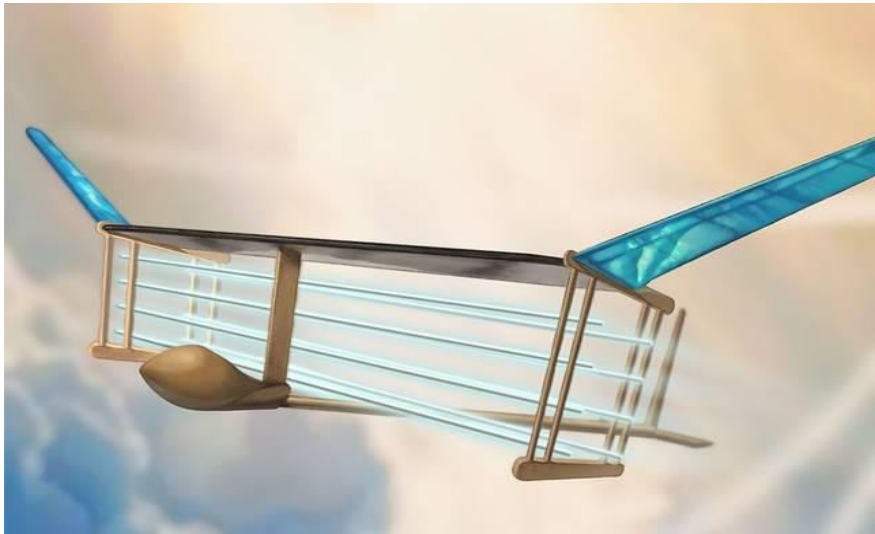


Fig. 3 The basic idea is that if you ionize air, which means removing electron from it, you can accelerate the air with an electric field.

For Example, suppose we carried out 10 test flights of the aircrafts, in which the plane flew around 60 meters in 12 seconds. At this speed, it has a thrust efficiency of 2.6%. As speed increases, the efficiency of the thrusts would also increase.

## V. APPLICATIONS

An ion-propelled aircraft or ion craft is an aircraft that uses electro hydrodynamic (ehd) to provide lift or thrust in the air without requiring combustion or moving parts. The electro aerodynamic-powered plane uses a propulsion system to fly, which opens up possibilities for aircrafts that are 'quieter, mechanical simpler' and do not produce fossil fuel emissions.

## VI. CONCLUSION

In this paper, we have discussed, ion thrusters in aviation applications with two examples RF Ion Thruster and Regular Plane. In brief with its schematic diagram. Types of ion thrusters are also explained which are electrostatic and electromagnetic ion thrusters. Both, the types are explained. Electrostatic ion thruster commonly uses the xenon gas and electromagnetic ion thruster use Lorentz force. And Regular plane gives a basic idea about how thrusters used in aviation applications.

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