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A Space-Flight Ship Travelling by a Plasma Rocket Engine from the Earth Ground to the Moon

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Abstract

Since a thrust of an ion rocket engine is much weaker than the one of a chemical fuel engine, nowadays, ion engines are used mainly in spaces where gravities are very weak. Here, as a powerful plasma rocket to make a heavy ship get out from the gravity-sphere of the earth without relying on an atomic power rocket, an ion-velocity booster is investigated. It is a main challenge how to protect the engine wall from the melting due to collisions of ions which grow into high-energy particles.

Keywords

Plasma Fuel Rocket, Space-Flight Ship to the Moon, Ion-Velocity Booster

1. Introduction

Just before and after the beginning of the 20th century when electrons and protons were found, many scientists had already thoughts that electric charged particles may be able to be used as propellants of a rocket by accelerating them with static electric fields [1] [2] [3] [4]. Researches of such an electric propulsion rocket (EP) began around the middle of the 20th century [5]-[10]. EP has been already accomplished in a large variety of physical different devices. For example, Resistojet (electric resistive heater), DC arcjet, Hall thruster, self-field magnetoplasma dynamic thruster (MPD), microwave electrothermal thruster (MET), etc. [11] [12]. Nowadays, various ion rockets play important roles as main engines for control of artificial satellites or for flights of space-ships to investigate aerolites or the planets. Since thrusts of the ion engines mentioned above are much smaller than that of a chemical fuel engine, at present, the ion engines are used only in the spaces where gravities are very week. So, regular researches to produce a powerful ion engine which makes use of enormous nuclear energy have now been continued toward actualization. However, here, we investigate a powerful plasma engine (an ion-velocity booster) unrelated to nuclear energy. It will be a dream of general people to go sight-seeing to the moon directly from the earth ground. The times will come in the 21st century. We also have the same dream and have attempted to design a space-flight ship to be able to carry people and lots of goods to the moon. We inquire into a space-ship of the weight 5000 ton (1 ton = 10^3 kg) which flies with rocket engines using plasma fuel (hydrogen plasma containing seeds, Na atom). To get an engine with very strong thrust, it is our plan to accelerate ions of a plasma by the use of an ion-velocity booster (a long tube) and to expel the ions as extremely high-energy particles. In this research, it has been the most sincere challenge how to reduce heating and damage of the engine wall due to collisions of ions which grow into particles having almost same temperature with inside a nuclear fusion reactor. Furthermore, it was a difficult point how to supply a plasma to the booster. For example, when combining the booster with MPD thruster which can expel a propellant plasma with the speed of about 10^5 m/s by the Lorents force due to the current and the self-induced magnetic field, significant amount of heat may generate and interaction between the magnetic fields of MPD and the booster may bring about unwanted effect on each technology's performance. Integrating two kinds of accelerators seamlessly without compromising the functionality of each system may require some sophisticated control system. So, we have adopted a simple way to make a gas (plasma, neutral atoms, seeds) gush directly from a plasma production room into the inlet of the booster.

2. A Basic Structure of the Booster

A general view of a space-flight ship is shown in **Figure 1**. The right and left long tubes are the ion-velocity boosters. Three symbols (up, down, →) indicate the directions in which MPD thruster expel the plasma jet. The water and the liquid nitrogen-cooled booster consists of 40 pieces of a part (shown in **Figure 2** and called Part) which are connected in series. In the liquid nitrogen-cooled system, we use a carburetor which is an industrial manufacture. That is an apparatus to gasify from a liquid nitrogen (−196˚C) into a nitrogen gas (−50˚C) and to spout the gas energetically. A cooling effect of this system will be more than the one of the water-cooling system. The central space (shown in **Figure 3**) of Part is a path through which a plasma and a solenoid magnetic field $\boldsymbol{B}_0\left(=\hat{y}0.3\,\mathrm{T}\right)$ pass. The central space has a square cross section. By the solenoid magnetic field near the inlet of the booster, neutral atoms are separated from a plasma and only charged particles (hydrogen ions and electrons) are sent into the central space of the booster.

To obtain the help of an air-lift in an atmospheric flight, the ship is equipped with huge main wings and tail wings. The 40 pieces of Part in the booster are called "part 1, part 2, …, part 40" in turn from the inlet. The wall of the central

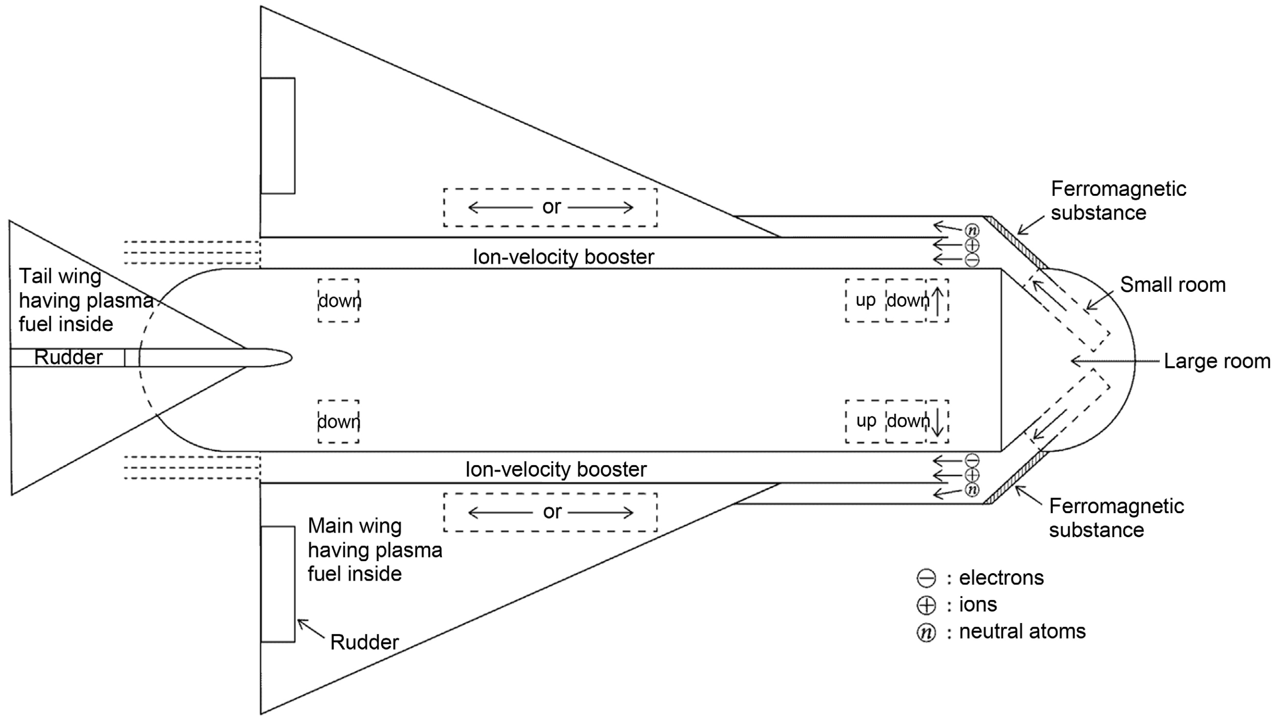

Figure 1. A general view of a basic structure of a space-flight ship to carry passengers, fuel and necessaries of life to the moon. Ferromagnetic substances are used only in the small parts which become the passing ways of the solenoid magnetic fields.

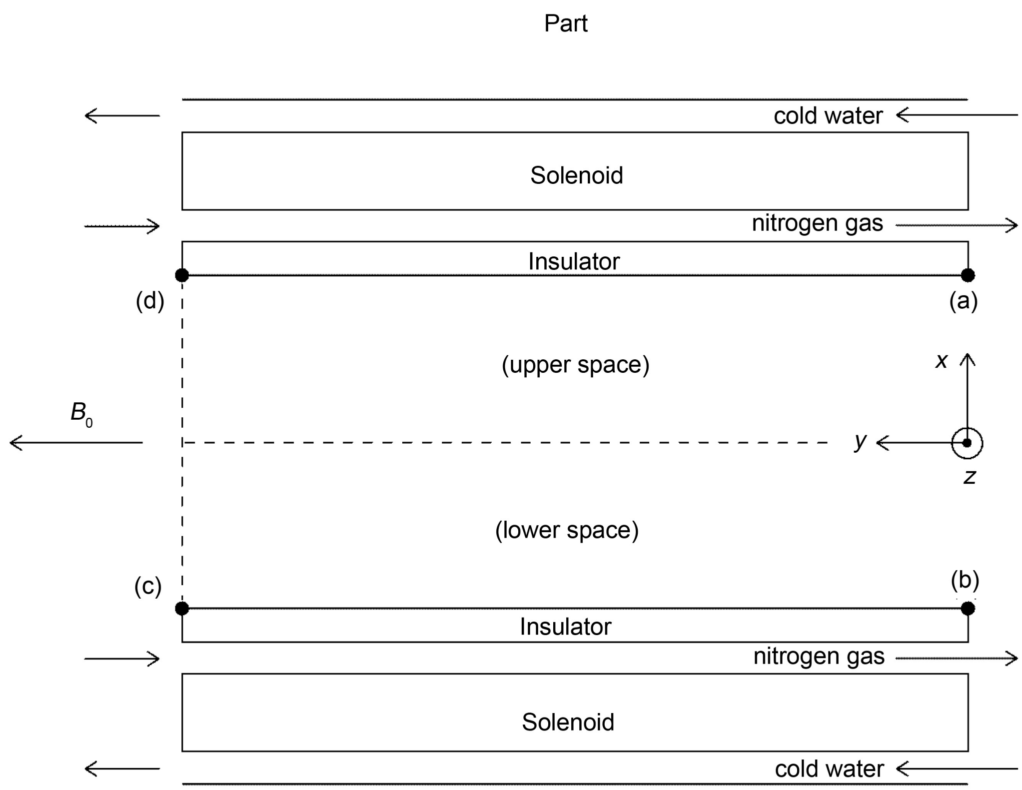

Figure 2. A side view of a part of the ion-velocity booster. In the upper space and the lower space of the part, the different electric fields are applied. In the ion-velocity booster, 40 pieces of this part are connected in series.

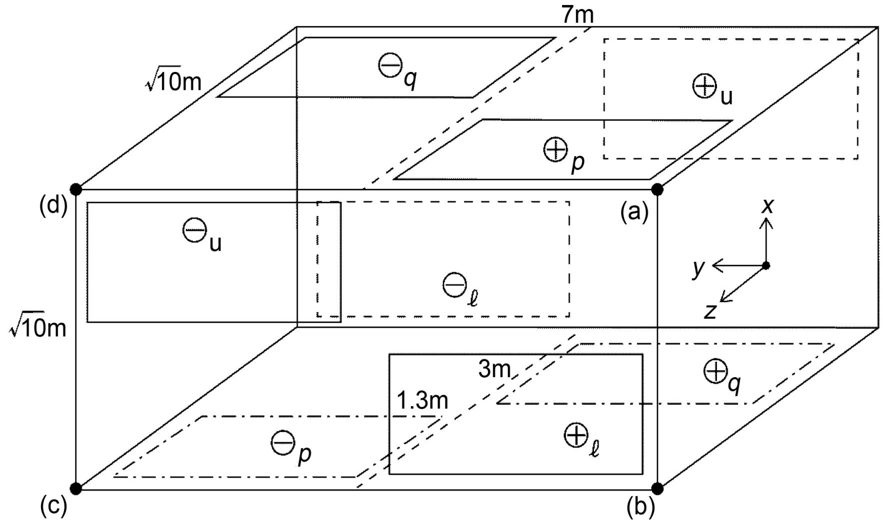

Figure 3. The above box ($10^{1/2} \times 10^{1/2} \times 7\ m^3$) is an oblique view of the central space of Part. Four points (a), (b), (c), (d) are ones which correspond to the positions of (a)-(d) of **Figure 2**, respectively.

space (shown in **Figure 3**) is made of an insulator plate, but some parts of four sides of the wall are cut off in order to insert four kinds of rectangle pair-electrodes:

$$\begin{cases} \text{anode} - \text{cathode} \\ \oplus_u - \ominus_u, \boldsymbol{E}_u = (\hat{y} + \hat{z})10^3\ \text{V/m in the upper half space,} \\ \oplus_\ell - \ominus_\ell, \boldsymbol{E}_\ell = (\hat{y} - \hat{z})10^3\ \text{V/m in the lower half space,} \\ \oplus_p - \ominus_p, \boldsymbol{E}_p = (\hat{y} - \hat{x})10^3\ \text{V/m in the right half space,} \\ \oplus_q - \ominus_q, \boldsymbol{E}_q = (\hat{y} + \hat{x})10^3\ \text{V/m in the left half space,} \end{cases}$$

where, $\boldsymbol{E}_{u,\ell,p,q}$ are electric fields which are applied by ($\text{anode}_{u,\ell,p,q} - \text{cathode}_{u,\ell,p,q}$), respectively.

When parts 1, 3, …, 39 with odd numbers use the electric fields ($\boldsymbol{E}_u$ and $\boldsymbol{E}_\ell$), parts 2, 4, …, 40 with even numbers use the electric fields ($\boldsymbol{E}_p$ and $\boldsymbol{E}_q$). We send a plasma to the booster by the following way: A gas (10 mmHg at 0˚C) is sent into the large room shown in **Figure 1**. The gas consists of hydrogen atoms and seeds (Na). After the seven percent (an ion density $n_i = 2.5 \times 10^{22}\ \text{m}^{-3}$) of hydrogen atoms have been ionized in the large room, the gas is sent to two small rooms little by little. And there, after "hydrogen atoms and hydrogen ions" have been heated to temperature $T_g = 1500\ \text{K}$, those (H, H^+, Na^+, electrons) are expelled to the inlet of the booster. The gushing velocity υ_g is 5 × 10^3 m/s (from $kT_g = (1/2) m_i \upsilon_g^2$, $k = 1.38 \times 10^{-23}\ \text{J/K}$: the Boltzmann constant, m_i = 1.67 × 10^{-27} kg: a hydrogen atom mass). Every construction-material of a rocket must be a durable and strong one against heating and mechanical stresses.

We now consider the case where those ions enter in the region of the electric field $\boldsymbol{E}_u = (\hat{y} + \hat{z})10^3\ \text{V/m}$. The ions get z and x components of velocities as well as acceleration in the y-direction.

Here, we set the following three assumptions:

1) For acceleration of an ion in the *y*-direction by $\hat{y}\cdot\boldsymbol{E}_{\mathrm{u}}$, a frictional force due to the Coulomb forces of other charged particles can be disregarded.

2) A drift velocity of ions and electrons in the -*x*-direction is $\left|\hat{z}\cdot\boldsymbol{E}_{\mathrm{u}}\right|/\left|\boldsymbol{B}_0\right|$.

3) A drift velocity of ions in the *z*-direction by $\hat{z}\cdot\boldsymbol{E}_{\mathrm{u}}$ is much smaller than $\left|\hat{z}\cdot\boldsymbol{E}_{\mathrm{u}}\right|/\left|\boldsymbol{B}_0\right|$, which is estimated from the theory in the case of a weakly ionized plasma.

When a hydrogen ion (the mass $m_{\mathrm{i}}=1.67\times10^{-27}\,\mathrm{kg}$, the charge q = 1.6 × 10^{-19} C) has passed part 1 (the length $\ell=3\,\mathrm{m}$ of the electric field $E_{\mathrm{y}}=\hat{y}\cdot\boldsymbol{E}_{\mathrm{u}}=10^3\,\mathrm{V/m}$) with the initial velocity $\boldsymbol{\upsilon}_0=\hat{y}5\times10^3\cos45^\circ\,\mathrm{m/s}$, a velocity $\boldsymbol{u}_1\left(=\hat{y}u_1\right)$ of the ion is

$$u_1=\left(\upsilon_0^2+\frac{2qE_{\mathrm{y}}\ell}{m_{\mathrm{i}}}\right)^{1/2}=7.6\times10^5\,\mathrm{m/s} \tag{1}$$

In the space with no electric field between part 1 and part 2, the ions do a uniform motion. Then, these ions are to enter into part 2 with "the velocity 7.6 × 10^5 m/s and a density $2.5\times10^{22}\times\left(5\times10^3\cos45^\circ/7.6\times10^5\right)=1.2\times10^{20}\,\mathrm{m}^{-3}$". An influence of the Coulomb force scattering on a drift velocity of the ions becomes smaller and smaller. When an ion with the initial velocity $\boldsymbol{\upsilon}_0=\hat{y}5\times10^3\cos45^\circ\,\mathrm{m/s}$ in part 1 has passed part 40, a velocity $\boldsymbol{u}_{40}=\hat{y}u_{40}$ of the ion becomes, substituting 40 × 3 m into ℓ of (1),

$$u_{40}=4.8\times10^6\,\mathrm{m/s} \tag{2}$$

It is noted that an ion temperature T_{i} corresponding to u_{40} is about 10^9 K which is to be a temperature inside a fusion reactor:
(from $u_{40}\simeq\left(8kT_{\mathrm{i}}/\pi m_{\mathrm{i}}\right)^{1/2}$).

In the upper space of part 1, an ion current density $\boldsymbol{i}_{\mathrm{x}}$ in the *x*-direction is, when the ion density n_{i} is tentatively 10^{22} m^{-3},

$$\boldsymbol{i}_{\mathrm{x}}=-\hat{x}n_{\mathrm{i}}q\frac{\left|\hat{z}\cdot\boldsymbol{E}_{\mathrm{u}}\right|}{\left|\boldsymbol{B}_0\right|}=-\hat{x}5.3\times10^6\,\mathrm{A/m^2} \tag{3}$$

This value is too large. Using $\boldsymbol{E}_{\mathrm{u}}$ in the upper space and $\boldsymbol{E}_\ell$ in the lower space will contribute to protect the upper plate and the lower plate from the damage which will be brought about by the huge ion current, through the forces of $\boldsymbol{E}_{\mathrm{u}}\times\boldsymbol{B}_0$ and $\boldsymbol{E}_\ell\times\boldsymbol{B}_0$. Any flow, perpendicular to $\boldsymbol{B}_0$, of the charged particles entering into the place with no electric fields is suppressed by $\boldsymbol{B}_0$. As the plasma goes to the outlet, the density distribution around the central axis is to become gradually larger, through the forces of $\boldsymbol{E}_{\mathrm{u},\ell,\mathrm{p,q}}\times\boldsymbol{B}_0$.

It is presumed that an ion current density in the *z*-direction will be much smaller than $\left|\boldsymbol{i}_{\mathrm{x}}\right|$. But, since ions grow extremely high energy-particles, we have set a following means in order to reduce the damage of the negative electrodes due to collisions of ions: The means is to change the pair-electric fields being used in each part "from ($\boldsymbol{E}_{\mathrm{u}},\boldsymbol{E}_\ell$) to ($\boldsymbol{E}_{\mathrm{p}},\boldsymbol{E}_{\mathrm{q}}$) or in the opposite way" every some time interval. It is considered to be the most sincere problem whether the operations of the pair-electric fields, the water-cooling system and the liquid nitrogen-cooling system can lengthen sufficiently the lives of the engine walls and the negative electrodes or not.

A part of ions recombine with electrons on the surfaces of the negative electrodes, but let us here expect that those recombined ions (hydrogen atoms) are to be ionized soon again by electrons. A jet mass m_0'' which is expelled from the small room to the inlet of the booster per unit time is, since the area S of the cross section of the central space is 10 m^2,

$$m_0'' = n_i m_i \left|\upsilon_0\right| S = 2.5\times10^{22}\times1.67\times10^{-27}\times5\times10^{3}\cos45^{\circ}\times10 = 1.48\ \text{kg/s} \quad (4)$$

The booster expels the jet mass m_0'' with the velocity 4.8 × 10^6 m/s from the outlet, per unit time. Though we presume that ions drag electrons, the masses of expelled electrons and the seeds have been neglected.

3. A Level Flight Parallel to the Ground

Disregarding the gravity and the air-resistance, the equation of motion [13] of the ship is

$$\frac{d\text{M}(t)\text{V}_{\parallel}(t)}{dt} = m_0\left(\upsilon_j - \text{V}_{\parallel}(t)\right) \quad (5)$$

where,

$\text{V}_{\parallel}(t)$: the velocity of the ship at time t,

υ_j: the velocity of the plasma jet expelled from the outlet of the booster (As already mentioned, we consider that ions always drag electrons and therefore the booster expels not ions but a plasma),

m_0: the mass $2m_0''$ of the plasma jet expelled per unit time (There are two pieces of the booster),

$\text{M}(t)$: $\text{M}_0 + \text{M}_f - m_0 t$ (M_0 is approximately the mass of the ship-body, goods, MPD thrusters, the solenoid and the nitrogen liquefying apparatus, M_f is the mass of the plasma fuel, $\text{M}_0 + \text{M}_f \simeq 5000$ ton).

Equation (5) can be rewritten as

$$\frac{d\text{V}_{\parallel}(t)}{dt} = \frac{m_0\upsilon_j}{\text{M}_0 + \text{M}_f - m_0 t} \quad (6)$$

The solution is, under the condition of "$\text{V}_{\parallel}(t) = 0$ at $(t = 0)$",

$$\text{V}_{\parallel}(t) = \upsilon_j \ell_n \frac{\text{M}_0 + \text{M}_f}{\text{M}_0 + \text{M}_f - m_0 t} \quad (7)$$

When

$$m_0 t / \left(\text{M}_0 + \text{M}_f\right) \ll 1, \quad (8)$$

Equation (7) becomes

$$\text{V}_{\parallel}(t) \simeq \upsilon_j \frac{m_0 t}{\text{M}_0 + \text{M}_f} \quad (9)$$

Substituting into (9)

$$\begin{cases} \upsilon_j = 4.8 \times 10^6 \text{ m/s}, \; M_0 + M_f = 5000 \times 10^3 \text{ kg}, \\ m_0 = 2m_0'' = 1.48 \times 2 \text{ kg/s} \simeq 3 \text{ kg/s} \end{cases}$$

we have

$$V_{\parallel}(t) = 2.9t \text{ m/s} \tag{10}$$

A necessary velocity $V_{\parallel esc}$ to get out from the gravity-sphere of the earth is, from the condition that the centrifugal force $(M_0 + M_f)V_{\parallel esc}^2/R$ (R: the earth radius 6.4 × 10⁶ m) is equal to the gravity $(M_0 + M_f)g$ (g: the acceleration of gravity 9.8 m/sec²),

$$V_{\parallel esc} = \sqrt{Rg} = 7.9 \times 10^3 \text{ m/s} \tag{11}$$

A time t_{esc} which is required for $V_{\parallel}(t)$ to become $V_{\parallel esc}$ is, from (10),

$$t_{esc} = \frac{7.9 \times 10^3}{2.9} = 2.7 \times 10^3 \text{ sec}$$

A quantity of the plasma fuel which is consumed for 2.7×10^3 sec is

$$m_0 t_{esc} = 3 \times 2.7 \times 10^3 = 8.1 \text{ ton} \tag{12}$$

The condition (8) is satisfied.

We ask for a time t_{sound}, for later discussion, that is required for $V_{\parallel}(t)$ to become the sound speed 340 m/s. From (10),

$$t_{sound} = \frac{340}{2.9} = 117 \text{ sec} \tag{13}$$

4. A Rising Motion Vertical to the Ground

Four MPD thrusters (down) are used. We use a MPD thruster which can expel the jet of the mass m_d with the velocity $\upsilon_{dj}\left(= \sqrt{2} \times 10^5 \text{ m/sec}\right)$ per unit time.

An equation of motion of the ship is

$$\frac{dM(t)V_{\perp}(t)}{dt} = 4m_d\left(\upsilon_{dj} - V_{\perp}(t)\right) - M(t)g, \tag{14}$$

where, $V_{\perp}(t)$ is a rising velocity of the ship. When $V_{\perp}(t) = 0$ at ($t = 0$), the solution of (14) is

$$V_{\perp}(t) = \upsilon_{dj}\ell_n\left(\frac{M_0 + M_f}{M_0 + M_f - 4m_d t}\right) - gt \tag{15}$$

When

$$4m_d t/(M_0 + M_f) \ll 1, \tag{16}$$

Equation (15) becomes

$$V_{\perp}(t) \simeq \upsilon_{dj}\frac{4m_d t}{M_0 + M_f} - gt \tag{17}$$

Asking for the minimum value $(4m_d)_{min}$ of $4m_d$ which satisfies ($V_{\perp}(t) \geq 0$), we have

$$\left(4m_{\mathrm{d}}\right)_{\min} = 0.346 \text{ ton/sec} \tag{18}$$

The consumed quantity for t_{sound} is 40 ton. This quantity is clearly too much. Then, we get the help of an air-lift ($\propto \rho \mathrm{V}_{\parallel}(t)^2$; ρ: air density) by huge main wings and tail wings. When the velocity $\mathrm{V}_{\parallel}(t)$ of the ship attains to the sound speed 340 m/s, let us design the forms of the wings so that the sum of the air-lift and the centrifugal force may become equal to the earth-gravity M(t)g. Here, we compare the fuel consumption quantity in a chemical fuel engine with the one of the MPD thruster. A jet velocity in a chemical engine seems to be about 4×10^3 m/s. Then, asking for the minimum value $\left(4m_{\mathrm{c}}\right)_{\min}$ of the quantity corresponding to $4m_{\mathrm{d}}$ which satisfies "$\mathrm{V}_{\perp}(t) \geq 0$" in (17), we have

$$\left(4m_{\mathrm{c}}\right)_{\min} = 12.2 \text{ ton/sec} \tag{19}$$

This is 35 times of $\left(4m_{\mathrm{d}}\right)_{\min}$.

5. Conclusion

We have inquired into the powerful plasma engine by which a ship of 5000 ton can get out from the earth gravity-sphere, without using enormous nuclear energy. However, since the booster, MPD thrusters and the nitrogen liquefying apparatus will consume a large quantity of electric power, the possession of nuclear energy may be required. For the dream of travelling an interplanetary space by a ship, a fission (or a fusion) propulsion engine has been pursued from around the middle of 20th century. As atomic power engines of continuous propulsion type, there are the gas-core nuclear rocket [14] and the magnetic confinement fusion (MCF) rocket [15]. The gas-core type uses energy from a fission reaction. The radiant energy is transferred from a high-temperature fissioning plasma to a hydrogen propellant. MCF also heats a propellant gas by radiant energy from the fusion reaction in a magnetic-mirror reactor. The energetic fusion plasma is mixed with a propellant hydrogen gas near the magnetic nozzle and the mixture is expelled along the magnetic lines. The temperature of a propellant gas is limited by the temperature limit of the construction-material surrounding the propellant gas. The ion-velocity booster also has met with a similar problem on the temperature limit. As already mentioned, the ion temperature near the exit of the booster is on the same level with inside a fusion reactor. So, we have mentioned a few preventive means to prevent the booster wall from melting. However, it is desired to furthermore increase the solenoid magnetic field. For the ion velocity-booster engine, we consider that it will be the last engineering means to insert (regardless of the old solenoid, electrically) not heavy superconducting coils in a few intermediate places of the old solenoid.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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