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Electromagnetic Propulsion Without Ionization

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When an alternating electric field is applied to a polarized or polarizable material such as pure water, the dipole can be made to rotate at high frequency. If an alternating and synchronized magnetic field is then applied at right angles to the electric field, a Lorentz force is generated which propels the dielectric fluid without the necessity for ionization and the consequential energy losses. The thrust is proportional to the polarization, the frequency of dipole rotation, and the magnetic field strength. A gaseous propellant consisting of water or a colloid spray can achieve useful exit velocities at megacycle frequencies with power consumption diminished relative to conventional electromagnetic propulsion systems. Finally, the concept is applied to a shuttle propulsion system reacting against air and water vapor and found to show promise in launching payloads into Earth orbit and beyond.

Nomenclature

a = particle radius
A = area
B = magnetic field strength
C = velocity of light
E = electric field strength
F = thrust
f = frequency
i = current
I = moment of inertia
J = quantum integer
k = Boltzmann constant
L = inductance
m = molecular mass
N = number of turns
P = polarization
P_e = electrode dipole moment
P_t = total beam power
q = charge
R_e = effective radius of force field
R_0 = vehicle radius
S = beam power intensity
s = charge separation distance
t = time, s
T = torque
U_i = ionization potential
V = volume
v = velocity of charge
V_e = exit velocity
w = angular frequency
X = accelerator length
$\ddot{X}$ = acceleration
α = polarizability
β = performance, N/W
ϵ = efficiency
ϵ_0 = permitivity constant
η = number density
ρ = density
θ = angular displacement
μ_e = electric moment
μ_i = induced dipole moment
μ_m = magnetic moment
μ_0 = permeability constant
μ_t = total dipole moment
ν = collision frequency
Ω = mass ratio

Introduction

A NEW concept of electromagnetic field propulsion is proposed in which dielectric or weakly conducting fluids are accelerated to generate the desired thrust levels. Unlike conventional electrostatic or plasma thrusters, no charging or ionization of the working fluid is required. Two application modes are explored:

1) Conventional propulsion—in which a selected propellant characterized by having a high total permanent or induced molecular dipole moment-to-mass ratio is accelerated by Lorentz forces to useful exit velocities.

2) Nonconventional field propulsion—in which shuttle propulsion of heavy payloads to Earth orbit is proposed using an electromagnetic field propulsion concept that reacts against a large volume of air and water vapor molecules in the atmosphere.

In this concept, the working fluid is accelerated yet each particle remains uncharged. Hence, one can expect thrust densities unaffected by space charge effects. Furthermore, since no ionization is required, the energy loss mechanisms associated with the ionization processes customary in mercury ion engines, for example, are eliminated. It appears possible to achieve molecular or colloid accelerations comparable to present thrusters.[1] To this end, the concept requires high angular rotations of the induced dipoles which exist in a gaseous state. The rotational energies are relatively insignificant; however, power is absorbed by the gas to maintain the dipole orientation against molecular collisions. Accordingly, a power source that generates megacycle electric and magnetic fields is required, and thus weight and efficiency tradeoffs must be made relative to conventional electrostatic ion and plasma thrusters.

In a shuttle propulsion application, the thrust is generated using an alternating voluminous force field that is externalized to intercept the maximum amount of ambient atmosphere or interplanetary mass. The dipoles are induced into rotation using an alternating Lorentz field or a beam of pulsed circular polarized microwave energy. The pulse rate or field frequency is controlled to achieve synchronized rotation of the atmospheric dipoles relative to the alternating high energy (10^{12} J) magnetic field. The Lorentz force couples to the vehicle and exerts its thrust with high mechanical efficiency. The thrust equation ($F = \dot{m} V_e$) is applicable wherein $\dot{m} \gg V_e$ and the velocity of ambient material is slow but the mass is several times the mass of the vehicle.

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Table 1 Properties of some common polar and nonpolar fluids

Substance	Permanent dipole moment, C-m	Polarizability, m^3	Induced dipole moment, 2×10^6 V/m	Dipole moment-to-mass ratio
Water	6.2×10^{-30}	18.6×10^{-30}	3.3×10^{-34}	2.1×10^{-4}
Ammonia	4.9×10^{-30}	27.8×10^{-30}	4.9×10^{-34}	1.75×10^{-4}
Hydrochloric acid	3.6×10^{-30}	33.1×10^{-30}	5.9×10^{-34}	5.9×10^{-5}
Nitrogen	...	22.1×10^{-30}	3.9×10^{-34}	8.3×10^{-9}
Oxygen	2 Bohr magnetron (magnetic)	...	...	...
Hydrogen	...	9.93×10^{-30}	1.76×10^{-34}	1.1×10^{-7}

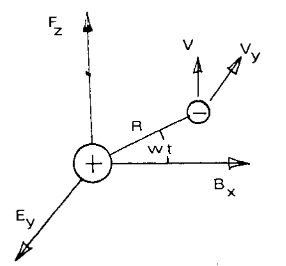

Fig. 1 Forces on dipole in alternating Lorentz field.

The technology level required to implement this force field concept of propulsion appears to be near at hand. Superconductivity permits fabrication of virtually lossless magnetic field coils with stored energies of 10^{12} J or greater. The development of multimillion ampere switches at microsecond rates permits the alternation of this high joule magnetic field. Alternatively, the field polarity is reversed by mechanical techniques in cases where conductivity is significant. The result is a field propulsion concept in which a pushing force is generated that acts in an outward or inward radially symmetric fashion and simultaneously on all elements of the ambient working fluid subjected to this pushing force field. The reaction is intense acceleration of the vehicle.

Basic Dipolar Propulsion Principles

Consider a free molecule in space that is subjected to an intense electric field, but still below the breakdown voltage characteristic of the fluid. If the molecule is like water (H_2O), it already has a permanent dipole moment given by:

$$\mu_e = qS \tag{1}$$

The dipole will tend to twist until it is aligned parallel to the field, experiencing a torque given by:

$$T = \mu_e XE \tag{2}$$

In addition to the permanent dipole moment, the molecule can have an induced polarization from the applied electric field.[2] The moment is given by:

$$\mu_i = \epsilon_0 \alpha E \tag{3}$$

The polarizability (α) is essentially the molecular volume. Hence, the total dipole moment is:

$$\mu_t = \mu_i + \mu_e \tag{4}$$

Additionally, conducting colloidal droplets can have an induced dipole moment given by:

$$\mu_i = 4\pi\epsilon_0 a^3 E \tag{5}$$

In a bulk gas, thermal collisions work against the orientation of the dipoles; hence a correction must be made. The result is the Debye equation

$$P = \epsilon_0 \eta (\alpha + \mu_e^2 / 3\epsilon_0 kT) E \tag{6}$$

where P is the polarization. This equation is valid up to 10^{10} Hz where the rotation of the dipoles can no longer keep up with the changing field. Table 1 lists some important ground state electrical properties of common fluids available for propulsion.[3] It may be possible to significantly increase polarizability by photoexcitation techniques which will be discussed in a future article.

If the applied electric field is alternating, the dipole can be made to rotate or oscillate at high frequency. If, now, an alternating magnetic field is applied in the same plane as the electric field and perpendicular to it, a net Lorentz force acts on the polar molecule that accelerates it at right angles to the plane of the electric and magnetic field. Figure 1 presents a vector diagram of the Lorentz forces acting upon a free dipole in an alternating crossed field. The force on each dipole is:

$$F = qVXB = qV_y B_x \tag{7}$$

where

$$\left.\begin{aligned} V_y &= wR\cos wt \\ B_x &= B_0 \cos wt \end{aligned}\right\} \quad wt = \theta$$

Hence, the force acting on each charge of the dipole is

$$F_z^+ = (+qwR\cos wt)(B_0\cos wt)$$

and

$$F_z^- = (-q)w(-R)(\cos wt)(B_0\cos wt) \tag{8}$$

Thus, a net force exists equal to their sum

$$F = F_z^- + F_z^+ = 2qwRB_0\cos^2 wt \tag{9}$$

but the dipole moment is $\mu_t = 2qR$, and finally

$$F = \mu_t B_0 w\cos^2 wt \tag{10}$$

The average or rms value of the force is found by integrating the force over a complete cycle and dividing by the period 2π, yielding:

$$\bar{F} = \tfrac{1}{2}\mu_t B_0 w \tag{11}$$

where w is the angular frequency of the Lorentz field and B_0 the peak magnetic field. The dipole oscillation is assumed to follow the electric field, although in practice there may be a phase lag, which, in any event, can be compensated for to get peak force.

For a bulk gas having a number density η, the body force is the summation of the molecular forces

$$F_b = \tfrac{1}{2}\eta\mu_t B_0 w \tag{12}$$

However, $\eta\mu_t$ is just the average dipole moment per unit volume or polarization P. Combining with the so-called Debye equation for polarization, the body force is:

$$F_b = \tfrac{1}{2}\epsilon_0\eta(\alpha + \mu_e^2/3\epsilon_0 kT)EBw \tag{13}$$

Unlike a plasma device, the body force increases the colder the gas is!

The power required to maintain a body force in a gas using this concept can be estimated next. During the application of an electric field to the dipole in the gas, energy is absorbed to: 1) polarize the molecule by induction ($\frac{1}{2}\epsilon_0 \alpha E^2$); 2) maintain the orientation of the polarized or polar molecule against thermal collisions ($\mu_t XE$); and 3) sustain the rotational energy of the dipole against thermal collisions ($\frac{1}{2}Iw^2$).

Hence, the total energy can be written:

$$U_t = \tfrac{1}{2}\epsilon_0 \alpha E^2 + \mu_t XE + \tfrac{1}{2}Iw^2 \tag{14}$$

During each collision, the dipole loses an amount of energy (ΔU), which must be resupplied by the field. The power is:

$$\dot{U} = (\Delta U)\nu_c \tag{15}$$

Evaluation of Eq. (14) for a typical gas such as water vapor shows that both the polarization energy term as well as the rotational term are negligible. Only the orientation energy term μXE is significant and even so amounts to about 6×10^{-8} eV/mole at breakdown voltage. Thus, during each molecular collision a certain fraction of the initial orientational energy must be provided by the field to restore the orientation.

In actuality, the various molecular energies are quantized and only discrete photon energies can be absorbed to stimulate molecular rotation, for example. Generally, these frequencies lie in the microwave region, which also happens to be the frequency region where useful body forces are established for ground state molecules.

The maximum polarization energy for a static field is limited to the ionization potential of the ambient gas

$$\tfrac{1}{2}\epsilon_0 \alpha E^2 \leq U_i \tag{16}$$

where U_i is the ionization potential. For nitrogen, $U_i = 15.5$ eV, hence, the electric field strength is limited to about 10^{11} V/m. This field is clearly much higher than that customarily available, and certainly higher than the breakdown voltage of the fluid. However, at high frequencies and beam power intensities such as those found in lasers, breakdown and ionization of a gas may be induced. While it is thus fully appreciated that under such conditions some ionization is possible, the emphasis of this paper is on exploring a new body force arising strictly from rotating dipole interactions. In practice, the JXB body force must be additionally considered in cases where gas conductivity becomes important.

Conventional Propulsion Application

Consider now the use of water as a propellant in this electromagnetic dipolar propulsion system. It has a permanent electric dipole moment equal to 6.2×10^{-30} C-m as shown in Table 1. When an electric field is applied to the molecule, an additional moment given by Eq. (3) is manifest, where α is 18.6×10^{-30} m^3. Hence, the total dipole moment is:

$$\mu_t = 6.2 \times 10^{-30} + 18.6 \times 10^{-30}\epsilon_0 E \tag{17}$$

For electric fields customarily available (10^6 V/m), the induced polarization is insignificant and only the permanent dipole moment remains.

The molecular dipole acceleration in an alternating Lorentz field is [Eq. (11)]:

$$\ddot{X} = \tfrac{1}{2}(\mu_e/m)wB \tag{18}$$

and the exit velocity is:

$$V_e = (2X\ddot{X})^{1/2} \tag{19}$$

where μ_e/m is the dipole moment-to-mass ratio. For water it has the value of 2×10^{-4} C-m/kg.

The possible molecular accelerations attainable can now be estimated. If one assumes a spiral coiled accelerating channel having the appropriate length with pancake superconducting coils on both sides generating a field of 10 T operating at 1 GH_z, the acceleration is

$$\ddot{X} = 2\pi \times 10^7 \text{ m/s}^2 \tag{20}$$

The length of the spiral accleration path required to achieve exit velocities of say 15,000 m/s is:

$$X \cong 2 \text{ m} \tag{21}$$

This result is not unreasonable. A 1-N thruster would then require a propellant (water) flow of 0.067 g/s. The power required to sustain this thrust level is at least

$$P_0 = \tfrac{1}{2}\dot{m}V_e^2 = 7538 \text{ W} \tag{22}$$

As mentioned, the rotational and polarization energies of the dipoles are insignificant. The orientational worst case energy per molecule is roughly $3/2kT$.

$$\Delta U = \mu_e XE = 4 \times 10^{-2} \text{ eV/molecule} \tag{23}$$

The number flow rate is

$$\dot{N} = \dot{m}/m_P = 2.23 \times 10^{21} \text{ molecules/s} \tag{24}$$

Hence, the orientational power is:

$$P_0 = \dot{N}(\Delta U) = 14.3 \text{ W} \tag{25}$$

which is insignificant. Some power is used to vaporize the water stored as a liquid into a vapor, estimated as follows:

$$P = H_V\dot{m} = 250 \text{ W} \tag{26}$$

where H_V is the heat of vaporization (J/kg). If the efficiency of the inverter is estimated at 75%, and assuming 1000 W to keep the coils in a superconductive state, a total input wattage of 12,000 W is required, providing an efficiency of 63%.

In Fig. 2, the performance of this concept as measured in specific impulse is presented vs the device characteristics; i.e., the product of the dipole rotation frequency, magnetic field, and channel length. Frequencies well into the microwave region are required to obtain molecular accelerations comparable to present electrostatic thrusters (10^9 m/s^2). If new propellants can be found or synthesized that have higher dipole moment-to-mass ratios, operation at lower frequencies would be possible.

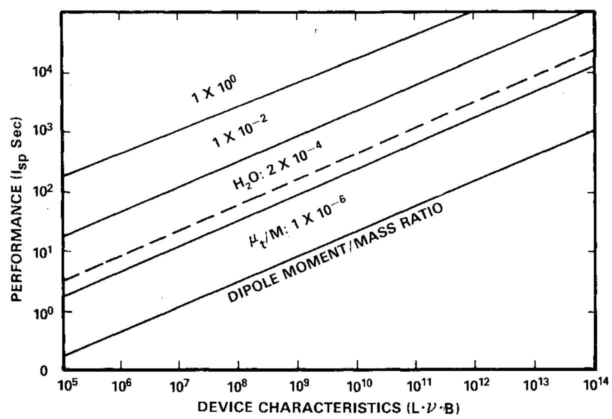

Fig. 2 Performance vs device characteristics.

Table 2 1-N-thruster design parameters—summary

Specific impulse	1500 s
Mass flow rate	0.067 g/s
Dipole moment/mass ratio	2×10^{-4} C-m/kg
Dipole rotation frequency	1 Gc
Accelerator length	2 m
Magnetic field	10 T
Power requirements	
Coil joule heating power (I^2R)	1000 W
Polarization power	Negligible
Orientational power	14.3
Rotational dipole power	Negligible
Beam kinetic power ($\frac{1}{2}MV^2$)	7538 W
Power for vaporization (H_VM)	250 W
Radiation loss	Minimal
Total	8802 W
Assume inverter at 75% efficiency	12,000 W input power
Efficiency (beam power/input power)	63%

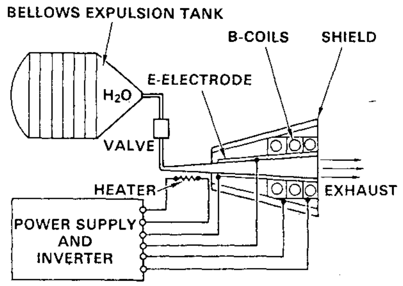

Fig. 3 E&M dipole propulsion concept features.

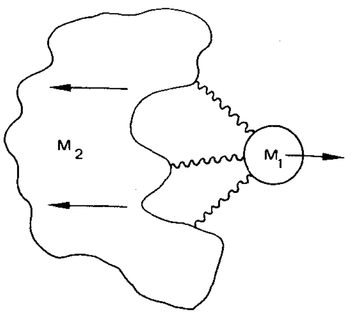

Fig. 4 Coupling of masses by field.

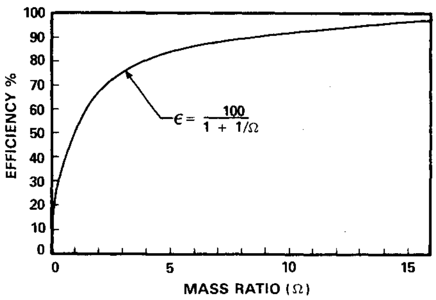

Fig. 5 Propulsion efficiency vs mass ratio.

The most significant advantage of this propulsion concept derives from the potentially lower power consumption required to achieve a desired level of thrust. The accelerating mechanism is essentially a noncollision process where thermal and radiative processes are not significant. The electric field applies a torque to the dipole, which does not directly effect the linear motion of its center of mass. Table 2 summarizes the design and performance characteristics of a 1-N thruster at 1500 s Isp. High beam power efficiencies are conservatively estimated, and if joule heating losses can be reduced, higher efficiencies may be possible.

Figure 3 shows a sketch of the electromagnetic dipole thruster in concept form. The thruster consists of a water-filled bellows expulsion tank, power supply source and inverter, heater elements for the vaporizer, the dipole angular accelerator, and magnetic thruster coils. The propellant is expelled at the desired flow rate and then vaporized. The water vapor molecules are then subjected to the alternating electric field to ramp them up to the matching angular frequency before the synchronized magnetic field is applied. The beam of water vapor then emerges into the vacuum of space and is dissipated harmlessly. The torque reaction on the thruster from the dipole rotation is insignificant. Obviously, the thrust density is not limited by space charge considerations, but only by the size and compactness of the electrode and coil arrangement, which are dictated by the inductances required to achieve the desired frequency and magnetic field strength.

Operation at high frequencies suggests the application of microwave generation technology. Most familiar is the application of microwave beams for random thermal heating of water-based substances (as in ovens). It is now being suggested that under controlled field conditions, instead of thermal heating alone, useful acceleration of water vapor for propulsion may be obtained. Moreover, additional studies should be conducted to survey candidate propellant materials characterized by having high polarization/mass ratios, as well as the other useful propellant properties. Operation at lower frequencies would then be possible. Finally, the design of the field coils should be examined to provide for compactness and to reduce weight.

Shuttle Propulsion Using E&M Force Fields

This development of a theory of force field propulsion begins from fundamental momentum and energy considerations. The approach will be classical, generally leaving relativistic considerations to other reports. Consider two mass assemblies as shown in Fig. 4, one of which (M_1) is the mass to be transported, and the other (M_2) is a lumped or distributed mass to which momentum is made to flow via some postulated "interaction" or "coupling" of M_1 and M_2. Mass (M_1) acquires momentum (P_1) and kinetic energy (K_1), and (M_2) achieves equal momentum (P_2) and a generally different kinetic energy (K_2). Now the amount of kinetic energy (K_1) obtained relative to the total kinetic energy generated is defined as the limiting mechanical efficiency:

$$\epsilon = K_1/(K_1+K_2) \tag{27}$$

where

$$K_1 = \tfrac{1}{2}M_1V_1^2 \quad \text{and} \quad K_2 = \tfrac{1}{2}M_2V_2^2 \tag{28}$$

and

$$P_1 = M_1V_1 = P_2 = M_2V_2 \tag{29}$$

or

$$M_2/M_1 = V_1/V_2 \tag{30}$$

where generally $M_2 \gg M_1$, and $V_1 \gg V_2$.

The ratio M_2/M_1 is defined as the field drive (FD) mass ratio (Ω). Combining Eqs. (27-30), the final expression for the limiting efficiency in terms of the FD mass ratio expressed as a percent is:

$$\epsilon = 100/(1+1/\Omega) \tag{31}$$

A graph of this equation is shown in Fig. 5. It can be seen from this equation that as the mass ratio approaches infinity, the reaction mass system acquires 100% efficiency as a limit.

This is ideally achieved when the space drive mass M_1 reacts against a body M_2 having nearly infinite mass, such as the universe. Even if the mass ratio is only unity, the system can still have a limiting efficiency of 50%. While if the mass ratio is zero M_1 acquires no kinetic energy. It should be emphasized that this efficiency is the *limiting* mechanical efficiency, while the actual efficiency must, of course, take into consideration such things as thermal and radiation losses.

In the real world environment, the medium in which the mass M_1 is to be propelled is fluid in nature and somewhat uniform in its distribution over relatively short ranges. In the hydrosphere, mass densities of 1000 kg/m^3 occur. In the atmosphere, there is a sea level density of 1.29 kg/m^3, which roughly decreases exponentially with altitude[4] until at about 30 km the density is under 0.2 kg/m^3. Finally, moving out into the region of interstellar space, the density reaches the highly rarified low of about 10^{-21} kg/m^3, one hydrogen atom per cubic centimeter! Utilization of this interplanetary and interstellar environment for propulsion represents a significant challenge to the technologist.

Now consider a spherical distribution of this media about the mass M_1. The medium has a density ρ uniformly distributed about M_1. Now hypothesize the existence of a "force field," the actual character of which will soon be described, that is capable of exerting a force on elements of the medium over a relatively large radial distance R from the central mass M_1. Accordingly, the mass can exert, via the force field, a force over a large volume of the medium to bring about M_1's efficient propulsion. For simplicity, assume this force field is everywhere uniform and ends abruptly at the distance R_e. The total mass M_2 of the medium within the confines of the force field is thus:

$$M_2 = (4/3)\pi\rho R^3 \tag{32}$$

where the volume occupied by the mass M_1 is neglected. The mass ratio is thus:

$$\Omega = M_2/M_1 = (4/3)\pi\rho R^3/M_1 \tag{33}$$

For illustration, consider a mass M_1 equal to 10,000 kg, which might be a convenient size for a space vehicle. Then the range of the force field R required to get various mass ratios (and hence, efficiencies) is found by solving Eq. (33) for R.

$$R = (3M_1/4\pi)^{1/3}(\Omega/\rho)^{1/3} \tag{34}$$

The graph in Fig. 6 shows the required range of the force field vs medium density for various mass ratios.

In the first part of this paper, the basic physics of a method of exerting a force on a medium capable of polarization was described. Coupled to an alternating electric and magnetic field, a Lorentz thrust without ionization is then possible. In this part, the concept is slightly modified in the use of circular polarized electromagnetic waves to rotate the dipoles in the medium, which may range from atmospheric to interstellar space. Alternatively, crossed electric and magnetic dipoles with external fields operating at high frequency can be utilized. The high energy magnetic fields (10^{12} J) are obtained using superconductivity. The alternation of this tremendous energy at high frequency is the area of technology that must be developed. The resultant force field propulsion system is characterized as follows:

1) Generates a body force that acts simultaneously on all elements of a volume of the medium over some effective range.

2) Because the reaction medium is significantly larger in mass than the payload, most of the total energy goes into the payload itself.

3) Exerts a unidirectional pushing or pulling force acting radially from the center of mass of the vehicle.

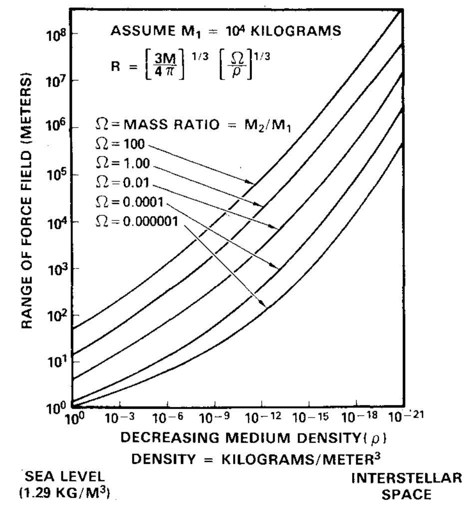

Fig. 6 Mass ratio vs range of force field.

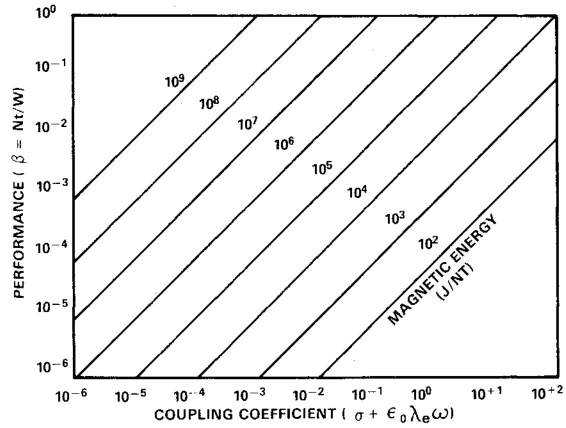

Fig. 7 Force field propulsion performance vs coupling coefficient.

The body force is given by Eq. (13), which can be written compactly as:

$$F_b = (PXB)w \tag{35}$$

In practice, some ionization will be present or created by thermal collisions driven or excited by the applied field; hence the actual body force is the sum of the contributions from conductivity and polarization:

$$F_b = (JXB) + (PXB)w \tag{36}$$

Note that the vector direction of each force is identical and additive to one another. Hence, ionization, if present, still makes a useful contribution to total thrust despite its added energy. The specific power is given by:

$$P_b = (J \cdot E) + (PXE)w \tag{37}$$

If the angles are all assumed to be right angles, then the thrust/power ratio β is:

$$\beta = F_b/P_b = B/E \tag{38}$$

If this equation is combined with Eq. (36), integrated over the total volume, and it is recalled that the magnetic energy density is $B^2/2\mu_0$, the performance equation is obtained

$$\beta = 2\mu_0(\sigma + \epsilon_0\lambda_e w)U_m/F \text{ (N/W)} \tag{39}$$

where λ_e is the electric susceptibility of the gas $\eta(\alpha + \mu_e^2/3\epsilon_0 kT)$ and U_m is the total magnetic energy stored in the field $\frac{1}{2}Li^2$. Figure 7 plots the performance of the field pro-

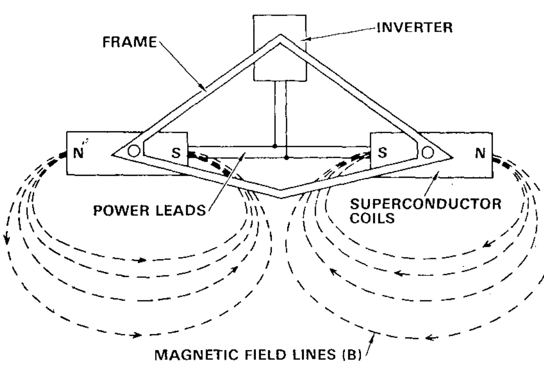

Fig. 8 Radial magnetic field coil configuration.

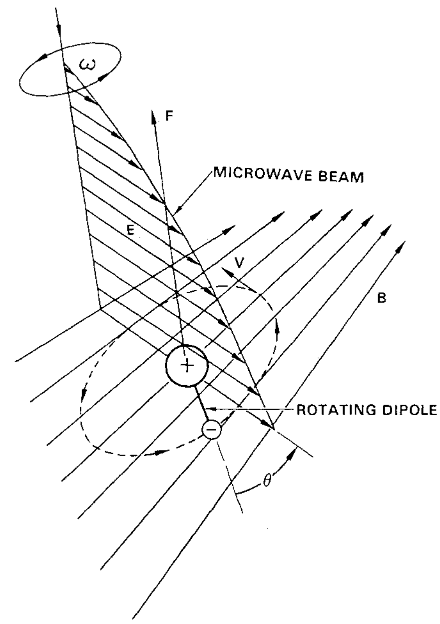

Fig. 9 Circular polarized beam interaction.

pulsion system for various conductivities and susceptibilities expressed by the coupling coefficient $\sigma+\epsilon_0\lambda_e w$ vs the stored magnetic energy/thrust ratio in joules/newton. It can be seen that even with coefficients of a fraction of unity (0.1-1) with stored magnetic field energies of $10^3=10^4$ J/N, excellent performance (several hundred watts/newton) is possible.

According to Ref. 5, current densities in type II superconductors of 15.5×10^6 A/cm^2 are possible. Hence, high stored magnetic energies in small coils are possible. The technological challenge is the alternation of this energy at very high frequencies.

The complete total thrust equation will now be derived and applied to a 10,000-kg vehicle. Assuming the field is always at right angles to the magnetic field, Eq. (36) becomes

$$F_b=\sigma EB+\epsilon_0\eta\left(\alpha+\frac{\mu_e^2}{3\epsilon_0 kT}\right)EBw \tag{40}$$

If the applied field E is removed, the polarization P of the gas will tend toward zero in a time increment called "the relaxation time." The reciprocal of the relaxation time gives the frequency at which resonant absorption of electromagnetic energy occurs with the dipolar molecule. To be more precise, quantum mechanical considerations require that the absorption of energy by the molecule occurs only at discrete frequencies:

$$\nu=[hJ(J+1)]/8\pi^2 I \tag{41}$$

where J is an integer ($J=1,2\ldots$), I the moment of inertia of the molecule, and h Planck's constant. The so-called molecular rotational spectra of a molecule define those discrete energy levels in which the absorbed energy is converted into rotational motion of the molecule which generally occurs in the microwave region of the electromagnetic spectrum.

The atmosphere, for example, consists of a number of different molecular species such as nitrogen (the primary constituent), oxygen, and water vapor, with smaller quantities of gases such as carbon dioxide and rare inert gases. The nitrogen has no permanent electric dipole moment and, therefore, the moment must be induced by the application of an intense electric field which cannot exceed the breakdown voltage of air, 20,000 V/cm. The induced electric dipole moment is presumed to originate by a shifting of the electron cloud surrounding the nuclei resulting in a displacement of the center of the negative charge from the positively charged nucleus, whereas the oxygen molecule is unique in that it possesses a permanent magnetic dipole moment equal to two Bohr magnetron. Finally, the water vapor in the atmosphere possesses a well-known permanent electric dipole moment due to the asymmetry of the two hydrogen bonds with respect to the oxygen molecule. The value of this electric dipole moment is equal to 1.87 D (wherein a debye is defined as 3.3×10^{-30} C-m). The water moleculae has a rotational absorption frequency[6] corresponding to a wavelength of 1.33 cm, and oxygen has one at 0.5 cm. The amount of water vapor in the air depends, of course, upon temperature, pressure, and the relative humidity conditions characteristic of the locale at the time of interest.

Accordingly, the mechanism that is postulated at this time for generation of thrust in the atmosphere is as follows: The water vapor and oxygen dipoles undergo intense rotations at some optimum applied frequency in the microwave region of the electromagnetic spectrum. The application of an alternating Lorentz field at this frequency induces strong accelerations of these molecules at right angles to the magnetic and electric fields. The water and oxygen molecules, in turn, collide with other molecules such as nitrogen (which are weakly coupled to the Lorentz field) and impart motion to them. Hence, the whole mass of air subjected to the oscillating Lorentz field is set in motion, which reacts upon the system producing the desired thrust.

If, for simplicity, one assumes that the force field around a vehicle is spherically distributed, the total force is found by integrating the body force over this volume:

$$F_t=\int_{R_0}^{\infty}F_b 4\pi R^2\mathrm{d}R \tag{42}$$

For crossed dipoles

$$E=P_e/4\pi\epsilon_0 R^3 \tag{43}$$

$$B=\mu_0\mu_m/2\pi R^3 \tag{44}$$

The result is

$$F_t=\left(\frac{\sigma+\epsilon_0\lambda_e w}{2\pi}\right)\frac{\mu_0}{\epsilon_0}\mu_m P_e\left(\frac{1}{R_0^3}\right) \tag{45}$$

In reality, of course, the integration is more complicated since there are cosine terms that correct for vector directions, and multiple species with different dipole moments and polarizabilities.

The preferred arrangement of the field coils is shown in Fig. 8. The coils are arranged with the polarity radially directed outward in the plane of the equator of the vehicle. The coils are made of type II superconductive material, and designed for very low inductance for resonate operation at the working frequency. Recently, titanium boride has been suspected of being superconductive at room temperature[7]; this would eliminate the associated cryogenics. The magnetic field intensity that is possible is limited to the elastic stresses the coils

Table 3 Shuttle propulsion design characteristics

Weight	10,000 kg
Environment	Sea level conditions at 300 K
Diameter	10 m (spherical)
Number density	2.68×10^{25} /m^3
Thrust	10^6 N
Vertical acceleration	1 G
Power input	200 MW at 100% efficiency
Performance	200 W/N
Field coil	
Material	Superconductive
Inductance	4×10^{-3} H
Current density	3.2×10^5 A/cm^2
Total current	3.2×10^7 A
Magnetic moment	2.5×10^9 A-m^2
Weight	3000 kg
Field energy density	2×10^7 J/N
Total magnetic field energy	2.1×10^{12} J
Coupling coefficient	1×10^{-3} mhos/m
Maximum magnetic field at vehicle radius	100 T
Electrode voltage	2×10^7 V
Electrode moment	2×10^{-3} C-m
Frequency (1.33 cm wavelength)	22.5 GHz

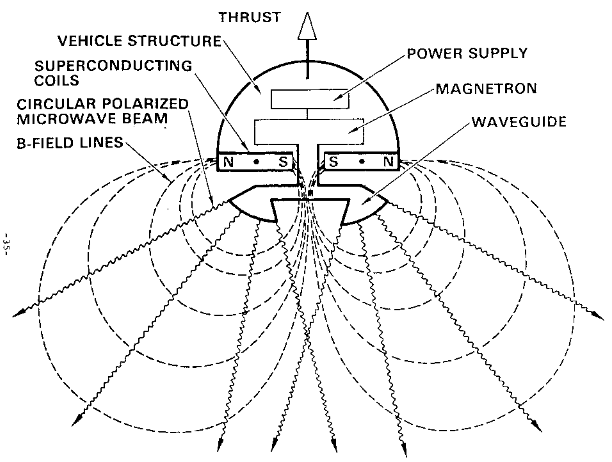

Fig. 10 E&M force field propelled vehicle.

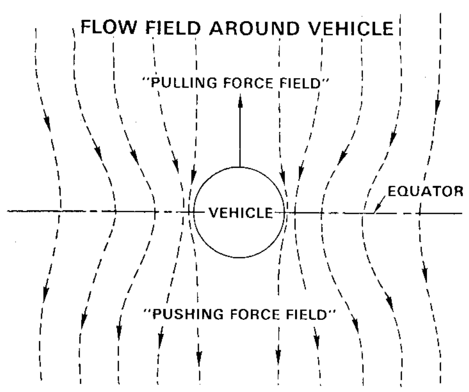

Fig. 11 Flowfield around vehicle.

can withstand. According to Fowler[8] for fields above 10^6 G, the coil itself is destroyed. The critical field for superconductor coils is currently limited to 38 T, which probably is a practical value to be used in engineering calculations. However, by the time this concept is implemented, fields up to 100 T may be a fact. In practice, the effective range of this high frequency field is limited according to the skin depth equation

$$\delta = (2/w\sigma\mu)^{1/2} \tag{46}$$

in cases where conductivity is important. While conductivity is deliberately ignored for the moment in this article, its positive effects of increasing the coupling coefficient and improving performance are not to be overlooked. Such effects must be weighed against the contraction of the skin depth and the decrease in atmospheric mass with which the field couples.

The expansion and contraction of the magnetic field will generate azimuthal electric fields which will rotate the dipoles to a certain degree. However, additional electric fields may be necessary. In Fig. 9, a technique of inducing dipole rotation using microwave beams is illustrated. The beam is circular polarized and can be thought of as a rotating electric field vector. The magnitude of the electric field is derived from the Poynting equation and Maxwell's velocity of light equation as

$$E = (S/\epsilon_0 C)^{1/2} \tag{47}$$

where S is the beam power intensity, given by

$$S = P_0/2\pi R^2 \tag{48}$$

where P_0 is the total beam power. Hence, the dipole moment of the molecules in the medium decreases with increasing distance R from the vehicle. The average angular frequency of the dipole arises from interaction with the pulsed microwave or steady-state radio frequency impulse. If the field is sufficiently intense, and the moment of inertia of the molecule very small, the dipole motion is assumed to follow that of the circular polarized beam and is therefore independent of distance over the effective range of the force field.

Table 3 summarizes the design characteristics of a shuttle propulsion system for a vehicle weighing 10,000 kg based upon E&M dipole rotations. The electrical conductivity of the gas is assumed to be zero. The performance at the stated conditions is 200 W/N and provides a vertical acceleration of 1 G. The frequency is chosen such that the field couples strongly with atmospheric water vapor (1% concentration) at a wavelength of 1.33 cm with a field attenuation of 0.3 dB/km. As the vehicle gains altitude and gas density decreases, the frequency is boosted to 0.5 cm or 60 GHz, and coupling with atmospheric oxygen takes place at 14 dB/km attenuation.

The design features of this vehicle are summarized in Fig. 10. Power is assumed to be supplied either by beamed energy, nuclear power, or an advanced chemical fueled magnetohydrodynamic power generator. Efficient conversion into electrical power in a small, compact device is required and believed to be technically feasible. The power is converted into a high frequency field to excite the superconducting coils as well as to provide the high voltage electric field. A microwave source such as a magnetron generates via the appropriate circular waveguides, a spherically symmetric beam of radiation that is approximately at right angles to the magnetic field lines. The microwave beam below the center of gravity is, say, right-hand circular polarized while the top beam is left-hand polarized. The force field above the vehicle thus "pulls" on the ambient gas while the field below "pushes." Hence, a large volumetric flow pattern is set up around the vehicle. As shown in Fig. 11, the external force field has the effect of creating its own convergent-divergent nozzle.

The eventual practicality of this propulsion concept requires pushing current technology to the limit in creating intense magnetic fields at high frequencies in a relatively strong but light and compact structure. The possibility of increasing the polarizability (which is equivalent to the molecular volume) of the ambient gas by photoexcitation should be examined in the future. By also considering the effects of conductivity, both the field requirements and frequency will be less stringent, another subject for consideration in a future article. Lastly, the biological effects of these high fields and frequency should not go unnoticed!

Summary

The force field propulsion concept described holds promise for lifting heavy payloads to Earth orbit and beyond. The only serious technological barrier to this achievement is developing the methods for reversing large magnetic fields at high frequency rates. If such barriers can be surmounted, high performance (efficient) propulsion may be possible. In any event, more conventional propulsion applications may show promise with proper propellant selection. The principle of the dipolar electromagnetic thruster shows promise for thrust generation with lower power requirements in future roles of station keeping and orbital maneuvering.

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